HYDRAULIC MODEL STUDY OF TRANING RIVER GANGA NEAR KANPUR

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

by

VIVEKANAND SINGH

to the

DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR

JULY, 1991

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Dedicated

To

My Parents and Wife

CERTIFICATE

It is certified that the work contained in the thesis entitled "HYDRAULIC MODEL STUDY OF TRAINING RIVER GANGA NEAR KANPUR" by Vivekanand Singh (Roll No. 8920317) has been carried out under my supervision, and that this work has not been submitted elsewhere for a degree.

July, 1991

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ABSTRACT

The water intake devices of Kanpur city's water works located at Bhairoghat on the right bank of River Ganga had adequate water supply till the mid-twentieth century. However, gradual migration of the river towards the left bank since the 1950's produced acute water crisis at water intake structures during the lean period of flow. This necessitated digging and maintaining a 6 Km long unlined canal to bring water from the left bank to Bhairoghat. Moreover, shifting of the water course towards the left bank caused impingement of flow and scouring at the earthen embankment of Kanpur-Lucknow road and railway bridge near Champapur. Both these problems may be rectified if the river course near Kanpur shifts towards the right bank.

A hydraulic model study was attempted here to train the river to flow near the right bank using permeable spurs for river training. A distorted scale model -- horizontal 1 in 9090 and vertical 1 in 130 -- with mobile alluvial bed was designed. Ganga river's flow data of 28 years, bed material data collected on site, and river planform and bed level data were used to simulate the river dynamics. Copper rods 4mm diameter, 4 to 5 diameters apart, were spaced in sequence to simulate proposed spur arrays in the river. Average and maximum annual flow hydrographs of 28 years were used to simulate the flow conditions in the river, using various types of spur array patterns. It was observed that a double array of permeable spurs near the left bank, and at acute angle to the bank upstream of Bhairoghat, was extremely effective in altering the river thalweg profile, shifting the river course towards the right bank and reducing scour at embankment. The

study indicates very positive results using permeable spurs for river training, but suggests the need for a more elaborate and detailed model study.

ACKNOWLEDGEMENTS

I express my sincere gratitude to Dr. T. Gangadharaiah for his constant help and encouragement, assiduous guidance and erudite suggestions throughout this endeavour. I am deeply indebted to him for his keen interest and concientious efforts.

My whole hearted thanks are due to all my teachers Dr. V. Lakshminarayana, Dr. K. Subramanya, Dr. S. Ramaseshan, Dr. S Surya Rao, Dr. B.S. Murty and Dr. B. Datta for teaching me useful courses in my M.Tech. Programme, and Dr. V Lakshminarayana, Dr. K Subramanya and Dr. S. Ramaseshan for useful suggestions and help on thesis work.

Thanks are due to the technical staff of Hydraulics laboratory of the Department of Civil Engineering, especially to Sri Suresh Kumar and Sri Satyanarayana, for the help I received from them during the experiments.

My special thanks are due to Mr Gautam Roy for his kind help and suggestions in the thesis report writing and Mr. S.K. Verma for his kind help, thanks are due to all my friends and the well wishers.

Finally, thanks are also due to Mr. B.P. Pant for his excellent typing and Mr. A.K. Ganguly for tracing and drawings.

VIVEKANAND SINGH

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

a_r - acceleration ratio ($a_r = a_n/a_m$)

A_* - Archimedes number ($A_* = Fr_*/Re_*^2$)

d_r - grain size ratio ($d_r = d_n/d_m$)

F_r - force ratio ($F_r = F_n/F_m$)

Fr - Froude number ($Fr \equiv v/\sqrt{gl}$)

Fr_* - modified grain Froude number ($Fr_* = \dfrac{\gamma_w}{\gamma_s - \gamma_w} \dfrac{v_*^2}{g\,d}$)

Fr_{*r} - grain Froude number ratio ($Fr_{*r} = Fr_{*n}/Fr_{*m}$)

F(x) - cummulative probability

g - gravitational acceleration

g_s - bed load transport rate per unit width

g_* - sediment transport number ($g_* = g_s/\rho_s d\, v_*$)

h_r - depth ratio ($h_r = h_n/h_m$)

l_r - length ratio ($l_r = l_n/l_m$)

N_r - manning-strickler roughness coefficient ($N_r = N_n/N_m$)

p - void fraction

P - exceedence probability

Q_r - discharge ratio ($Q_r = Q_n/Q_m$)

q_s, q - volume per unit time per unit width of sediment, of water

Re - Reynolds number ($Re = vl/\nu$)

Re_* - grain Reynolds number ($Re_* = v_* d/\nu$)

r_{hy} - hydraulic radius

Re_{*r} - grain Reynolds number ratio ($Re_{*r} = Re_{*n}/Re_{*m}$)

S_r - bed slope ratio ($S_r = S_n/S_m$)

$t_{s,r}$ - sediment time scale

$t_{h,r}$ - hydraulic time scale

T - return period

V_r - velocity ratio ($V_r = V_n/V_m$)

V_* - shear velocity ($V_* = \sqrt{\tau_o/\rho}$

σ - standard deviation

ρ_w, ρ_s - density of water, of sediment

$\Delta\rho$ - difference in mass density

ρ_r - density ratio ($\rho_r = \rho_n/\rho_m$)

μ - dynamic viscosity

ν - kinematic viscosity

τ_o - wall shear stress

γ_w, γ_s - specific weight of water, of sediment

ϕ, ψ - dimensionless bed load transport function according to H.A. Einstein

Subscript

m - model quantity

n - prototype quantity

r - relative quantity = prototype/model quantity

w - water

s - sediment

CHAPTER I

INTRODUCTION

1.1 GANGA RIVER PROBLEMS NEAR KANPUR

River Ganga meanders or braids in most places in the plains of Uttar Pradesh. Near Kanpur city, the river has a wide section but the thalweg profile, marking the water course during the lean summer months, meanders far away from the city towards Unnao. This was not always so; till 1956, the flow path was along Kanpur side, and the water intake structures near Bhairoghat could draw enough water for the city's major domestic and industrial water needs. However, the summer water course having shifted towards Unnao, water is now brought to the intake structures by a 6 Km long channel. The regular maintenance and desilting operations of this channel being costly, the city's engineers and planners have long sought a viable alternative to this arrangement. Figure 1.1 gives the location of River Ganga near Kanpur.

A second related problem is the severe scour at embankment near Champapur built for the road and railway bridges connecting Lucknow and Kanpur. The bridges, located about 5 Km downstream of the city's water works are on the extreme right of the flood plain, whereas the thalweg profile immediately upstream of the bridges is on extreme left as can be seen in Figure 1.2 which gives the planform details of River Ganga near Kanpur. Thus the flow turns sharply skirting the guide banks, before

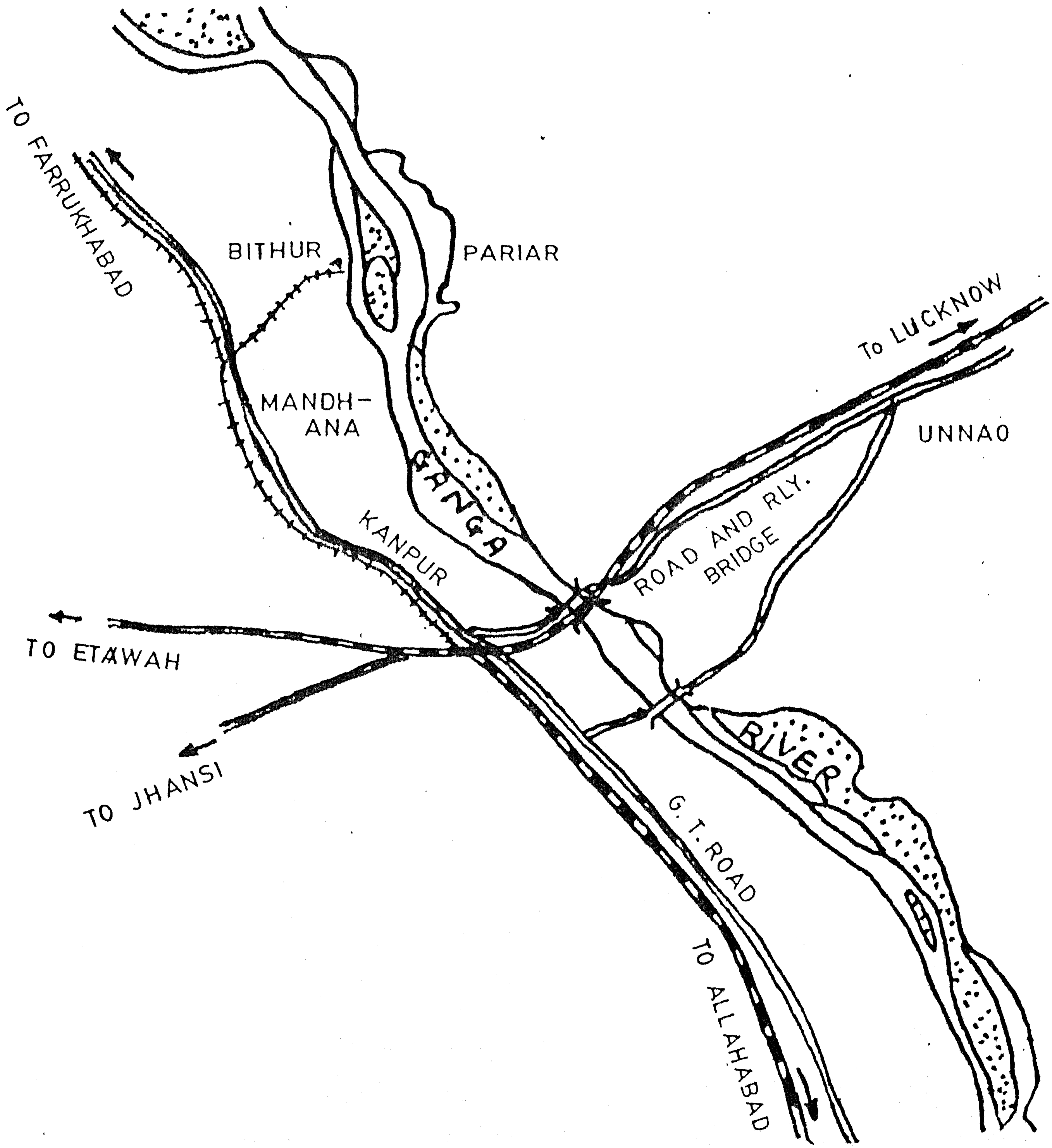
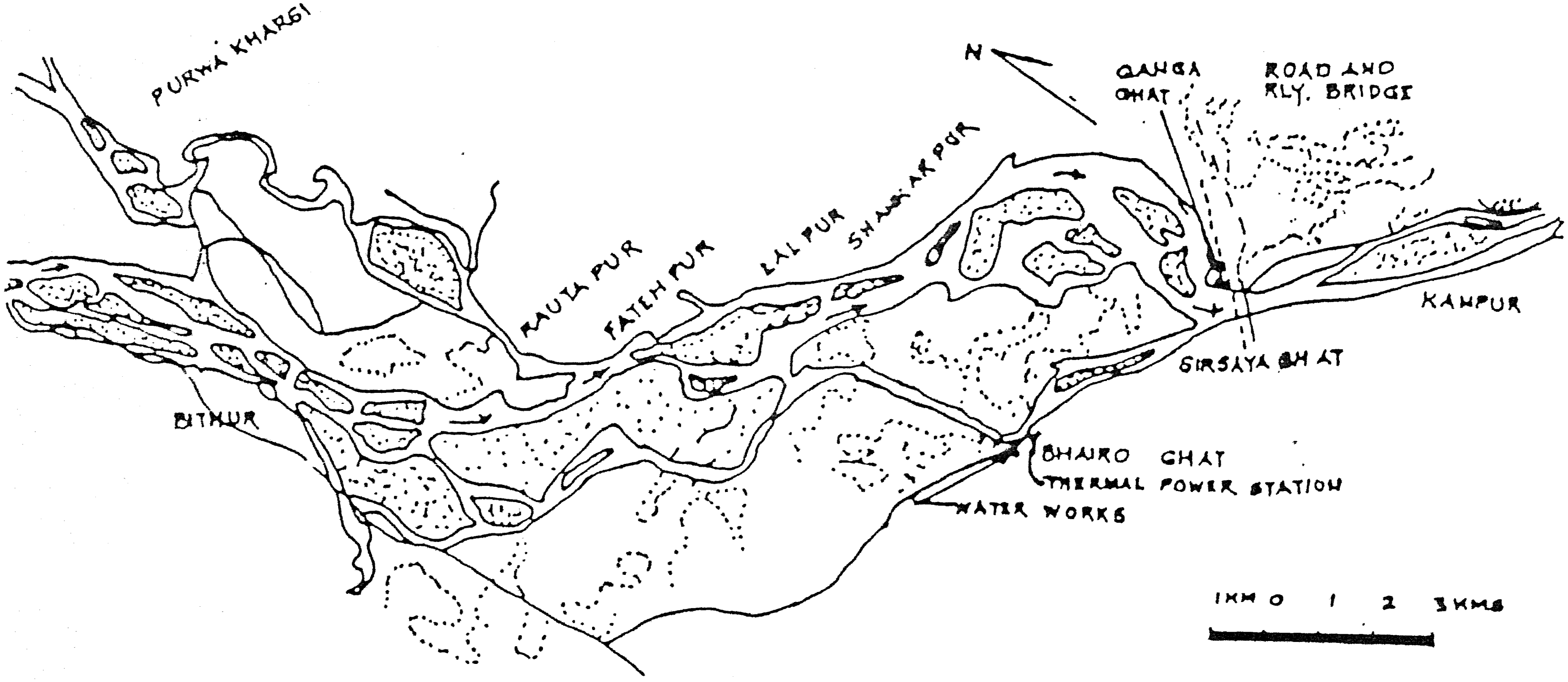


FIGURE 1.1 PLAN VIEW OF RIVER GANGA NEAR KANPUR SHOWING LOCATION OF ROAD AND RAILWAY BRIDGES.



PLAN SHOWING GANGA RIVER COURSE AT KANPUR (1982)

FIGURE 1.2 PLAN SHOWING GANGA RIVER COURSE AT KANPUR (1982)

turning left again, almost at right angles, to flow under the bridges. These sharp changes in flow direction cause excessive scour near the nose of guide bank. During high flood the severe scour causes danger to the embankment. These problems prompted the model study of River Ganga near Kanpur.

1.2 OBJECT OF STUDY

The aim of this work is two-fold. First, is to make available sufficient flow during the lean period at Kanpur city's water intake structures; second, to protect the guide bank of bridge and embankment from the severe scour. Both these objects were hoped to be achieved by a simple and relatively inexpensive river training method.

A laboratory study was planned to achieve the above objects. A distorted mobile bed model from upstream of Bithur to the road and railway bridges was planned. The use of permeable spurs was contemplated to divert the lean flow towards Kanpur bank. This was expected to ensure lean period flow at or near the water intake structures and also to avoid the severity of scour near railway bridge guide bank and embankment both during lean and flood flow periods.

.3 PRESENTATION OF THE REPORT

The thesis is presented in six chapters. The first hapter introduces the problem and the thrust of the present work. he second chapter briefly describes the relevant concepts and

knowledge of river modelling based on literature. In Chapter 3 a comprehensive description of the prototype problem, historical information, morphological and hydrological features are presented. The fourth chapter documents the prototype data used and their sources, and the design of experiments. In Chapter 5, the experiments have been described in detail, and the results analyzed. The important conclusions and limitations of this work, and suggestions for further work are listed in the concluding chapter (Chapter 6).

CHAPTER II

LITERATURE SURVEY

2.1 INTRODUCTION

A river is a natural water course carved on land over a long period of time, and conveying water from upstream sources (reservoirs, icemelt, etc.) or from precipitation in a catchment (surface run-off or subsurface flow) to a downstream surface water body. The diversity of factors and the complexity of their interactions that govern a river's contemporary status -- the morphology of the land, the extent and distribution of its water sources, the history of its development, the effect of manmade developments, the mechanics of water movement, the sediment carried into it by overland flow and strong winds, ambient conditions such as temperature, and even rotation of the earth on its axis -- makes it a most complex process for scientific study. While a river may be thousands of years old and a thousand kilometers long, the hydraulic engineer's interests and knowledge are usually limited to much shorter life-spans and lengths of rivers. Thus the hydraulic river researcher can delineate several important variables that characterize its regime, such as water and sediment discharges, valley slope, roughness, its three-dimensional geometry (namely planform, and cross sectional dimensions). While conceptually the flow processes in a river may be well understood, the actual quantitative relations between different variables are difficult to determine. In practice, a large number of empirical or semiempirical relations (such as

Manning's resistance equation, sediment transport relations, river regime formulae) are used to define the river regime and to predict changes in river behaviour [Leopold and Wolman, 1964, Jansen, et al. 1983; Knighton, 1984]. Consequently, mathematical formulations are not often adequate, and physical (scale) models may be used to predict changes in river behaviour, particularly before attempting to modulate or control actual river behaviour.

2.2 RIVER MORPHOLOGY

Rivers are characterized by both time varying and spatially varying quantities. The water and sediment discharges vary seasonally and annually. The river course, on the other hand, is usually non-uniform. Planform studies on rivers have delineated three major patterns, -- straight, meandering and braided, as illustrated in Figure 2.1. Straight rivers are found mostly on steep slope, but hydraulically such rivers may not be uniform due to the formation of step-pool systems or other non-uniformities in cross section.

Meandering rivers are very common on alluvial plains. When once a river deviates from its axial path, a curvature is developed (either due to its own characteristics or due to the impressed external forces) and the process moves down-stream by building up shoals on the convex side by means of secondary currents. The formation of shoals on the convex side results in further shifting of the outer bank by eroding on the concave side. Formation of successive bends of reverse order may lead to the formation of a complete S-curve called meander. When consecutive

curves of reverse order connected with short straight reaches, called crossings, are developed in a river reach then the river is stated to be a meandering river. Some useful ways of characterizing a meandering river are given below.

Thalweg : It is the line of maximum depth of stream along which the flow moves in lean period also.

Meander length (M_L) : It is the axial length of one meander, i.e., the tangential distance between the corresponding points of a meander.

Meander belt (M_B) or meander width : It is the distance between the outer edges of clockwise and anticlockwise loops of a meander.

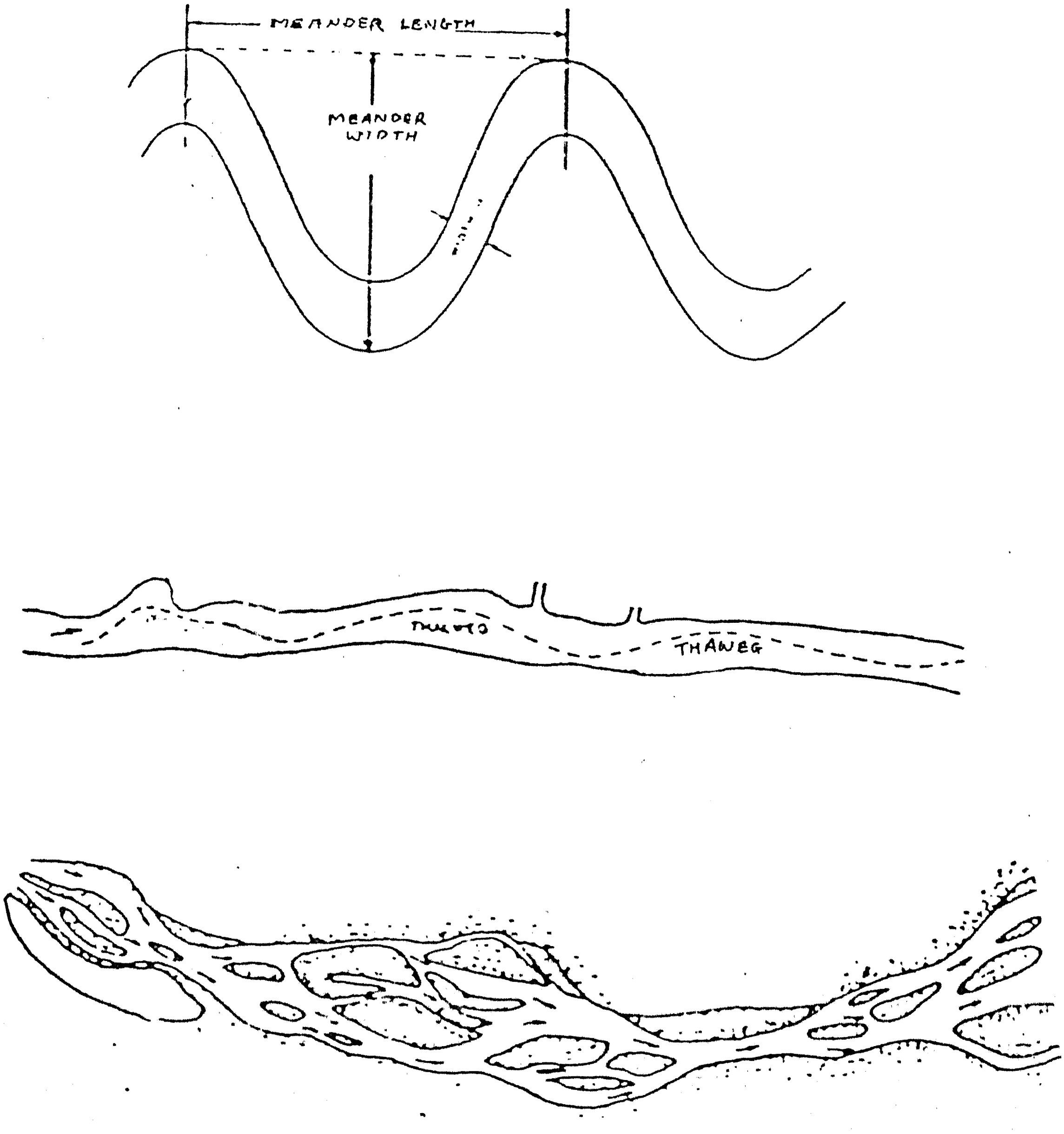
Meander Ratio (M_B/M_L) : It is the ratio of the meander width to the meander length.

Sinuosity : It is defined as the ratio of thalweg length to the valley length.

Tortuosity : $$\frac{\text{thalweg length} - \text{valley length}}{\text{valley length}} \times 100$$

Braided rivers or streams may also be observed on alluvial plains, and they are common near tidal outlets of rivers. A braided river can be defined as one which flows in a number of channels around alluvial islands. Figure 2.1 shows a typical braided reach of an alluvial stream.

Laboratory studies on river patterns have been conducted extensively in this century, particularly since Friedkin's study on river meandering [1945]. Field observations also have led to considerable insight and knowledge of river morphology in relation



Braided stream:

FIGURE 2.1 DEFINITION SKETCH FOR MEAND E RING AND BRAIDED STREAMS

to some dominant variables (Leopold et al., 1964, Knighton, 1984]. However, neither is the mechanism of morphological adjustments of a river fully understood, nor is there a reliable method to predict morphological patterns and changes accurately.

2.3 RIVER MODELLING

2.3.1 Scale models and mathematical models :

There are two main types of mobile bed models : mathematical model and scale model (or physical model). Analog models are of little use since they can not mimic the complex mechanism of river adjustments.

(i) Mathematical model : Certain problems in river engineering can be conveniently investigated by means of mathematical models. It is a model using mathematical relationships to represent the prototype. A fundamental pre-requisite of mathematical model is a satisfactory quantitative mathematical description of the physical processes involved. This description very often consists of a system of ordinary partial differential equations together with suitable boundary conditions and other data.

(ii) Physical model : A physical model is a precision device used in order to predict the behaviour of a physical phenomenon. Unlike analog model, it uses the physical properties and behaviour of modelling materials to represent the prototype [ASCE Task Committee, 1982]. The principal difference between mathematical modelling and physical modelling consists in the fact that a mathematical model

requires the formulation of equations which describe the phenomenon or flow field whereas it is sufficient for the hydraulic model to identify the acting forces and from these to formulate similarity parameters.

The relative merits of the above two types of models may be described as below.

(i) From the numerical point of view three dimensional time dependent computation will be out of the question for some time, at least for practical purposes. But solution of two dimensional time dependent problems are within the capability of existing computers. Physical models can be used to solve, both two and three dimensional problems, but their applicability is selective depending on the hydraulic conditions.

(ii) From physical point of view the process of turbulence is not yet fully understood. This means that the formulation of momentum transfer or mass transfer by turbulence contains empirical elements which limit range of application.

If one is faced with the decision to solve a problem either by means of a hydraulic model or by means of numerical model, one has to consider a variety of aspects as criteria in the decision process. The consideration of principal limitations may exclude a priori the one or the other type of model for certain problems, and which degree of accuracy or resolution is required from the model. The most important role in the decision making is played undoubtedly by the limiting factors of either type of

model.

Table 2.1 gives a comparative chart of the factor limiting the usage of hydraulic (scale) and numerical (mathematical) models [Kobus, 1980].

Table 2.1 Limiting factors for live-bed models

Hydraulic model	Numerical model
Principal Limitations	
Model size (laboratory)	Storage Capacity
Discharge (pumping capacity)	Computational speed
Energy head (pumping capacity)	Incomplete set of equations
Model laws	Turbulence hypothesis
Practical Limitations	
Minimum model scale	In simplified set of equations : -accuracy of assumed relationships -availability of coefficients
Model size (upper limitations)	-space and time resolution (lower limitation)
Measuring method and data collection	Numerical stability and convergence of the solution scheme
Availability of boundary and initial conditions	Availability of boundary and initial conditions

2.3.2 Physical models

A model in its widest sense is a simplified representation of a subject, state or event. Models may be similar or dis-similar. In similar models, all model parameters exhibit a certain relationship to the corresponding parameters in nature or prototype, which is determined by one or several model

scales. In dis-similar models the above requirements is not or only partially satisfied.

Hydraulic models are small scale reproductions of nature in the laboratory. In hydraulic model testing,usually model fluid used is water due to its being easily available, cheap and simply replaceable. However, the similarity requirements do not prevent the use of other fluids and may be advantageous in some cases. For example, similarity of sand transport in waterhas been achieved in small scale models by means of the transport of coal dust in glycerin.

2.3.3 Similarity mechanics

The model and prototype should have similar properties. And this similarity between model and its prototype is called similitude. For absolute similitude between a model and the prototype, the following types of similarities should exist.

i) Geometric similarity : This is the similarity of form which exists between model and prototype, if the ratio of corresponding linear (cartesian) dimensions of the model and prototype is constant. If the geometrical length is l_n in nature and corresponding length in model is l_m, then length scale number $l_r = l_n/l_m$.

ii) Kinematic similarity : This is the similarity of motion which exists when the ratio of corresponding kinematic quantities at corresponding points of the model and prototype are the same i.e., velocity, acceleration, etc.

Velocity scale number $V_r = V_n/V_m$

Acceleration scale number $a_r = a_n/a_m$

iii) Dynamic similarity : This is the similarity of masses and forces which exists between model and prototype when

(a) The ratios of masses of corresponding fluid particles in motion are the same.

(b) The ratios of forces on corresponding fluid particles are the same. Dynamic similarity includes geometric and kinematic similarities.

If Fn is the force acting in nature and Fm is the corresponding force in model, then force scale number F_r is

$$F_r = F_n/F_m$$

Dimensional analysis allows the formulation of criterion for dynamic similarity, since all relationships derived by dimensional analysis are independent of the absolute scale, they must be applicable for both small scale model and prototype dimensions.

A dimensional analysis leads to the conventional and well-known fluid mechanics characteristic numbers and model laws. By considering a fluid element of density ρ with a reference length l and reference velocity v under the influence of viscous forces, one obtains by dimensional analysis a fluid mechanics characteristics number as a ratio of inertial and viscous forces

$$Re = \frac{\text{Inertial reaction}}{\text{viscuous force}} = \frac{\rho v l}{\mu} \tag{2.1}$$

Re is known as Reynolds number. Very small Re characterize by definition flows in which viscous forces dominate and inertial reactions are negligible, as for instance in Darcy flow; flows in which the viscous forces are negligibly small in comparison to the inertial reaction, as for instance in fully turbulent pipe or channel flows, have high Re.

Corresponding dimensional considerations for a fluid element with inertial reaction under the influence of gravity forces yields another characteristic number, Fr.

$$\text{The force ratio Fr} = \frac{\text{inertial reaction}}{\text{gravity force}} = \frac{v}{\sqrt{gh}} \qquad (2.2)$$

Fr is called Froude number, which plays a dominant role in hydraulic modelling, as for instance in flows with a free surface. Negligible influence of gravity in comparison to inertial reaction corresponds to very large Froude numbers, whereas very small Froude numbers correspond to an overwhelming influence of gravity forces.

2.3.4 Model laws

Reynolds model law : In flows with significant viscous effects, Re has to be kept the same in model and prototype. Apart from geometric similarity, this requires in addition satisfaction of the Renolds model law

$$\frac{Re_n}{Re_m} = Re_r = \frac{\rho_r V_r l_r}{\mu_r} = 1$$

This law is satisfied if the velocity in the model is chosen such that their results

$$\frac{V_n}{V_m} = \frac{l_m}{l_n} \times \frac{\rho_m}{\rho_n} \times \frac{\mu_n}{\mu_m} \text{ or } V_r = \frac{\mu_r}{\rho_r l_r} \qquad (2.3)$$

If the model and prototype fluid are same, as in many laboratory experiments, the velocity number V_r becomes $1/l_r$

This implies that in a small scale model the resulting velocities must be larger than in the prototype.

Froude model law : For gravity-driven flows geometric similarity and Froude number must be preserved in model and prototype. Hence

$Fr = V_r/\sqrt{g_r h_r} = 1$. Since $g_r = 1$,

$$V_r = h_r^{1/2} \qquad (2.4)$$

2.3.5 Fixed bed models

'Fixed bed' refers to a bed whose roughness characteristics do not change due to the flow. In general models whose beds and banks can not be eroded are called fixed bed models. Such models are useful in the investigation of problems covering long regions of a river in which variations in bed configuration are not considered. Such models are used in the following studies :

i) To study changes caused by placing obstacles to flow like dams, piers etc.

ii) Effect on navigation conditions and backwater profiles during floods.

<u>Distorted and undistorted models</u> : To model water movement, it is necessary to ensure Froude number similarity. In an undistorted model the vertical and horizontal scales are identical, i.e. $l_r = h_r$, and according to Froude relation

$$V_r = h_r^{1/2} \text{ or } l_r^{1/2} \text{ and } Q_r = l_r^{5/2}$$

The model is perfectly defined by the only choice of the geometric scale number l_r. Then it is necessary to verify that frictional forces are scaled in the same manner as the inertial reactions. It means three conditions have to be fulfilled.

i) The Froude number must be the same in model and prototype.

ii) The roughness of the model must be correct.

iii) The flow in the model must be turbulent.

The difficulties commonly observed are :

i) Problem of measurements because depths and velocity will be small.

ii) The Renolds number in the model is not high enough to guarantee a turbulent flow, unless model fluid is different.

iii) The roughness of the model may not conform to prototype roughness.

To overcome the above difficulties in a scaled down model a solution consists in distorting the model by exaggerating the model depth. In these distorted models it is necessary to distort the slope in order to overcome the high resistance and also to provide a sufficiently high value of the Reynolds number to ensure turbulent flow conditions.

Distortion of slope can be estimated from Manning's law as

$$\frac{S_n}{S_m} = \left[\frac{v_n}{v_m}\right]^2 \cdot \left[\frac{N_n}{N_m}\right]^2 \cdot \left[\frac{h_n}{h_m}\right]^{4/3} \quad (2.5)$$

and

$$\frac{N_n}{Nm_m} = \left[\frac{l_m}{l_n}\right]^{1/2} \Big/ \left[\frac{h_m}{h_n}\right]^{2/3} \quad (2.6)$$

2.3.6 Mobile bed models

These are models of channels and streams, meant for investigating problems involving erosion, transportation and deposition of material of the channel bed. These models are very difficult to design. It is known that bed load is moved due to the tractive force exerted by the stream. When geometrically similar models are made, the tractive force available is usually insufficient to produce corresponding bed material movement when sand is adopted as the bed material. Hence in order to provide adequate tractive force mobile bed models are generally made distorted so as to provide steeper slopes. It is possible to bring down the value of the tractive force and, hence the extent of model distortion, if lighter materials of specific gravity greater than unity are adopted, eg. bakelite powder, pumice, coal dust, stone dust, wax balls, glass beads, plastic grains, etc.

It is also important that the scale selected is such that it provides a sufficiently high value of Renolds number to ensure turbulent flow, even at minimum discharge condition.

<u>Distorted mobile bed models</u> : Models of rivers and harbours are usually constructed by different scales for horizontal and

vertical dimensions to remove possible surface tensile effects and to maintain turbulent flow condition as exists in the prototype. Hence vertical scale is exaggerated resulting in a distorted model. In principle it is hydraulic similitude and not geometric similitude, which is the main governing factor in model design. Hence it may be necessary to adopt distorted models. The following types of distortion may be adopted.

i) Geometrical distortion : This is a distortion introduced by adopting different scales for horizontal and vertical dimensions.

ii) Configuration distortion : In this case the bed slope of the model is increased; otherwise the model is geometrically similar.

iii) Hydraulic distortion : In this type of distortion some hydraulic quantity, say velocity or discharge, may be changed.

iv) Material distortion : This type of distortion involves the use of material different from those in the prototype. Surface roughness or the medium in which the model works may be changed.

Merits of distorted models :

i) Higher Re in the model (especially to avoid laminar flow in flood plains).

ii) Improvement of relative accuracy of measurements.

iii) Shortening of model test durations.

iv) Decreasing of the importance of water losses in the model.

Demerits of distorted models :

i) Due to unequal horizontal and vertical scales the pressure and velocity distributions are not truly reproduced in the model.

ii) The wave pattern in the model will be different from that in the prototype due to depth distortion.

iii) Slopes, bends and earth cuts are not truly reproduced.

2.3.7 River models

For a river model with mobile bed the similarity requirements for sediment transport must be satisfied in addition, and the simulation of transport process requires furthermore the proper reproduction of density currents, turbulent dispersion process and reaction and exchange processes.

Water flowing in rivers transports solid material of various kinds and rates. Whereas the upper river reaches contain mostly coarse material, which at the larger slope is transported as bed load, the lower reaches contain usually finer materials, the motion of which is mostly in suspension. The sediment transport, which varies with discharge conditions, causes changes in bedforms, which can affect changes of the entire river course in the untrained river.

A great number of different investigations have been devoted to the solution of sediment transport problems. Whereas in the former times mainly empirical approaches were attempted, theoretical investigations have led in recent years to an essential expansion of our knowledge of sediment motion. Although

the sediment transport equation allows a rough estimate, it is usually not possible to calculate accurately the mutual interaction between river bedforms and discharge distribution. Therefore, the solution of difficult problems of river hydraulics requires often the use of models with mobile bed. Whereas in model tests with fixed bed the Froude model law is sufficient, model investigations with mobile bed must satisfy additional conditions with regard to the horizontal and vertical length scales and with regard to the bed materials. Procedure for obtaining dynamic (mobile bed) river model scales using dimensional analysis have been outlined and further discussed in the appendix.

2.4 TRAINING WORKS AS RIVER AID

River engineering works may vary greatly in size and in their effect on a river's behaviour. They may provide a strictly local improvement which hardly changes in upstream or downstream river reaches; or they may be designed to completely alter a river regime, thus affecting the river over almost its entire length. Whatever their scale may be, however, river improvement schemes always need careful consideration and a scientific as well as practical approach.

River training, in its wider aspects, covers all those engineering works which are constructed on a river, so as to guide and confine the flow to the river channel, and to control and regulate the river bed configuration, thus ensuring safe and effective disposal of floods and sediment loads. Stabilizing and

raining the river along a certain alignment with a suitable water ay is the first and foremost aim of river training. The ultimate im of river training is to achieve permanent stability of the iver. Here, stability of a river means that the river attains an quilibrium state, and no significant change occurs in its lignment, slope, regime etc.

River training works commonly involve groynes and spurs. here are two types of spurs used in the field, namely (a) mpermeable spurs, and (b) permeable spurs.

a) Impermeable spurs : are also called solid spurs or embankment spurs. These spurs may be rock fill embankments, armoured with stone pitching, concrete blocks etc. These spurs are called "imperemeable" because they do not allow any significant flow through them.

(b) Permeable spurs : Permeable spurs do permit restricted flow through them. These spurs are more or less temporary structures and are susceptible to damage by floating debris etc. Permeable spurs simply obstruct the flow and reduce its velocity, causing silt deposition in the vicinity. They are, therefore, best suited for rivers carrying huge sediment load. Permeable spurs do not change the flow abruptly as is done by impermeable spurs, and hence, intense and serious eddies and scour holes are not developed.

In this study permeable spurs are used as river training aid to control alignment and bank scouring.

CHAPTER 3

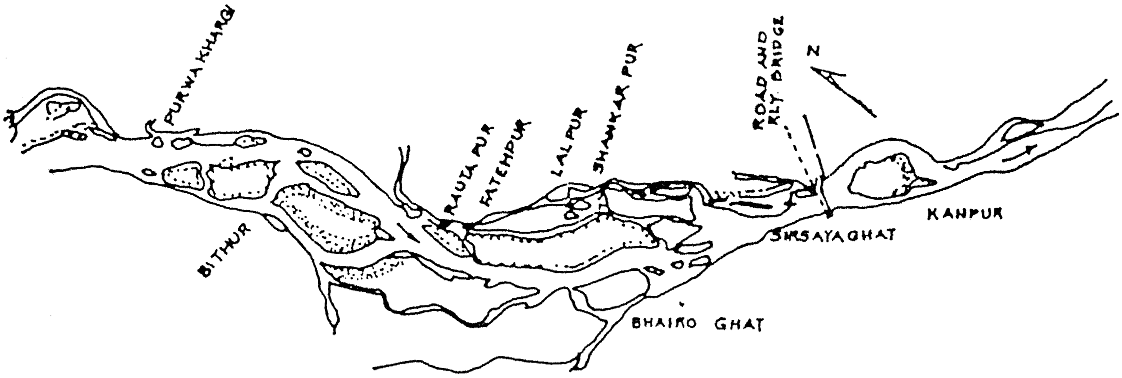
FEATURES OF THE PROTOTYPE PROBLEM

3.1 HISTORY OF COURSE OF GANGA RIVER SINCE 1910 NEAR KANPUR

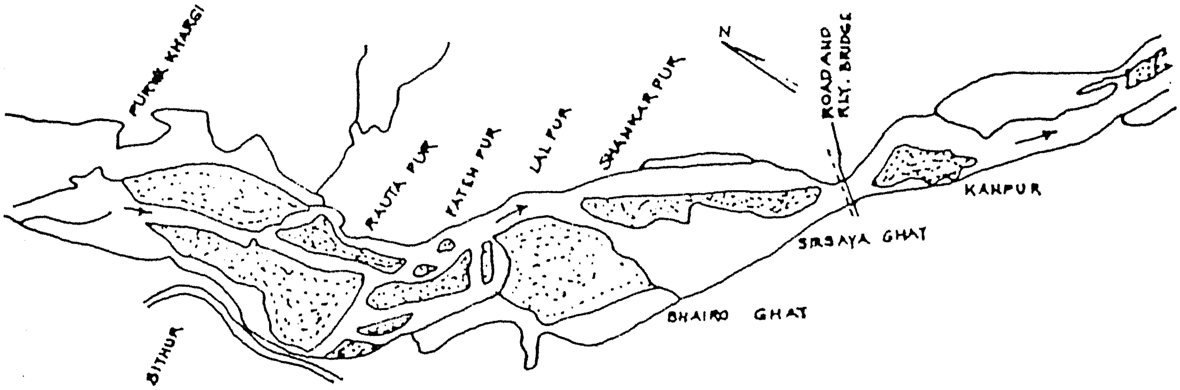
The meander pattern of Ganga river in the twentieth century has changed considerably as shown by records [Hegde, et al., 1989]. Figure 3.1 gives the flow path of River Ganga near Kanpur from 1910 to 1982. Figure 3.2 indicates the thalweg profile during 1947 to 1982.

In 1910-11, a clear meander pattern was observed in Ganga river making a perfect northward loop between Purwa-Khargi and Rautapur, and another loop was observed between Rautapur and Bhairoghat which was reverse loop curving southwards with point of inflexion at Rautapur. Due to this meander pattern the main current up to 1912 was flowing along the right bank where Kanpur city is situated. Thereafter it was observed that the Ganga river showed signs of shifting towards the left bank. But the shift was very slow. Near about 1945, the shift was more pronounced and for the first time the problem of water scarcity was felt at the water intake of city water supply work and thermal power station which are located on the right bank of Ganga river at Bhairoghat.

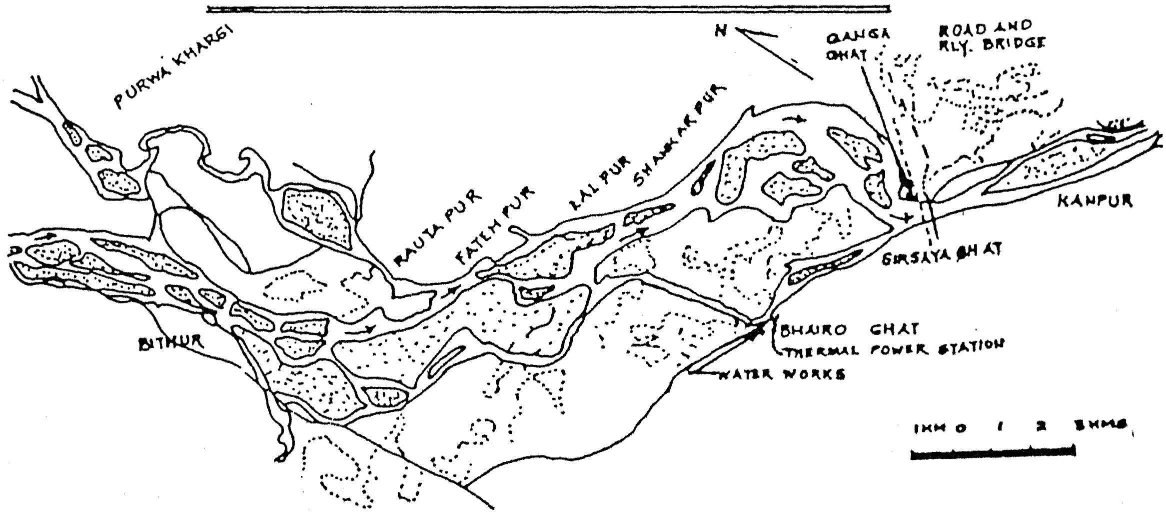
Near about 1953 the problem was further aggravated. To overcome the difficulty a channel was excavated to carry a part of river flow from left bank to the intake of water work and thermal power station. This process has been continued since that time. But after every monsoon the channel was silted up and it has to be dredged.



PLAN SHOWING GANGA RIVER COURSE AT KANPUR (1910-11)

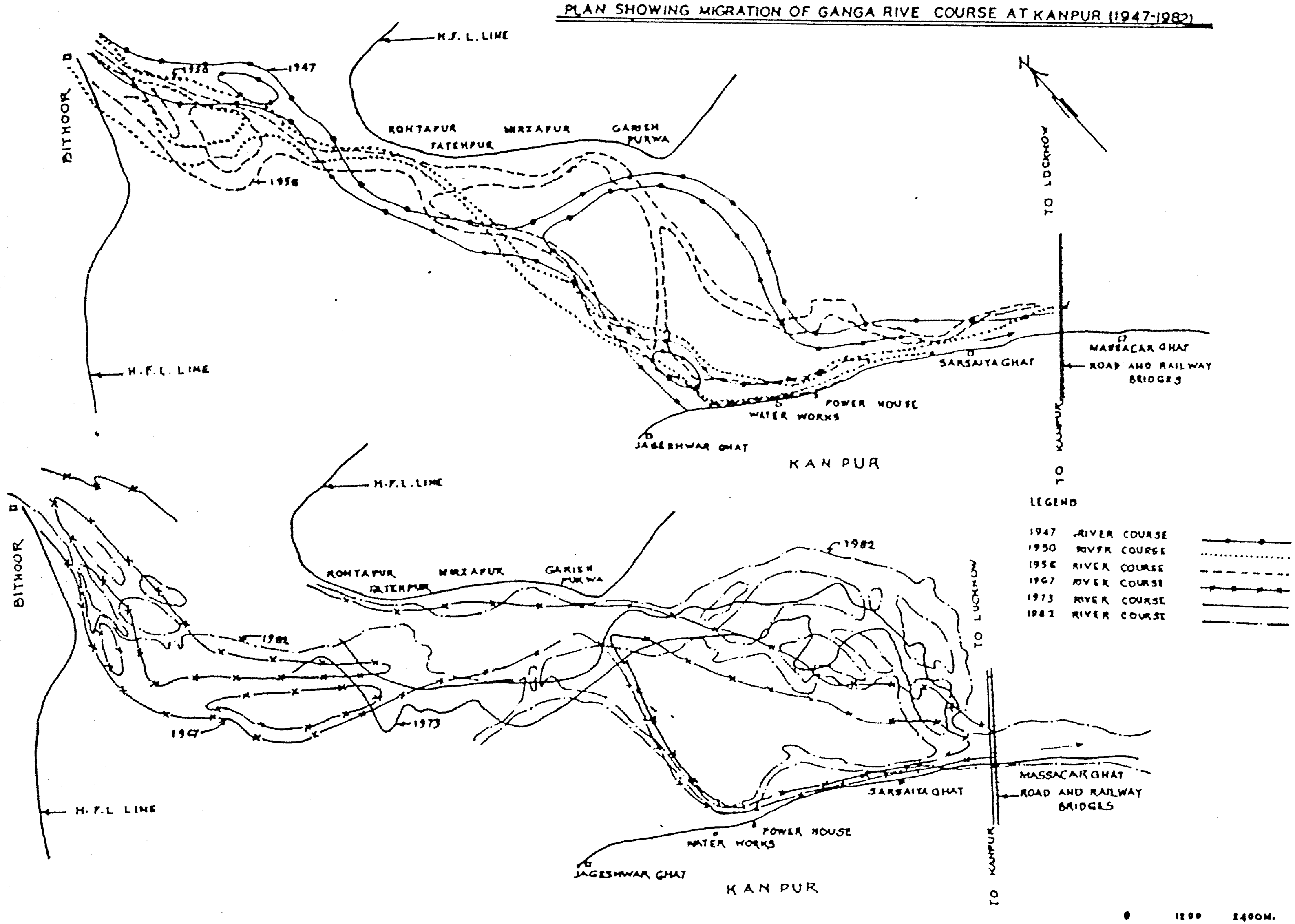


PLAN SHOWING GANGA RIVER COURSE AT KANPUR (1954-56)



PLAN SHOWING GANGA RIVER COURSE AT KANPUR (1982)

FIGURE 3.1 FLOW PATH OF RIVER GANGA NEAR KANPUR FROM 1910 TO 1982.



Migration of Ganga River Course at Kanpur (1947-1982)

FIGURE 3.2 THALWEG PROFILE DURING 1947 TO 1982.

Thereafter the main flow gradually shifted away from Kanpur and erratic movement of the meander continued. A survey conducted in 1982 showed a considerably transformed river configuration with a clearly discernible meander only upto Fatehpur. Downstream of Fatehpur, the river had severely eroded the left bank in a huge circular arc between Shankarpur and Gangaghat and several flow channels were formed with numerous shoals big and small in the bed. The transformation in the meander between 1910 and 1982 between Purwa-khargi to Rautapur is quite remarkable as would be evident from the following characteristics [Hegde, et al., 1989].

Parameters	1910-11	1982
Radius of curvature	7.83 Km	6.03 Km
Meander length	12.0 Km	8.0 Km
Meander width	1.5 Km	1.0 Km

3.2 MORPHOLOGICAL FEATURES OF RIVER GANGA NEAR KANPUR

The valley of the Ganga in a considerable length upstream and downstream of Kanpur is characterized by high firm bank on the right and low gently sloping bank on the left. Between Bithur and the railway bridge the river flows along the left bank. The right bank is resistant to erosion while the left bank, though composed of stiff hard clay, is comparatively easily erodible except in the reach between Rautapur and Shankarpur. During the last 30 years large areas on the left bank between Shankarpur and railway bridge were under severe erosion at different times.

Width of the valley varies greatly, being 6.5 Km at ithur, 9.5 Km at Rautapur and Bhairoghat and 3.5 Km at arsaiyaghat.

Downstream of Bithur, the right bank turns sharply to he south and the river leaves the right bank and crosses over to he left bank near Rautapur. This is a significant topographical eature that has a considerable influence on the river behaviour n the reach between Fatehpur and railway bridge.

Between Rautapur and Fatehpur the river had always been ore or less at the extreme left of the flood plain with the esult that all the spilling during flood took place on the right de over a large area right upto Baikunthpur on the right bank. is caused building up of flood plain only on the right side, and e huge Baikunthpur bar gradually developed in size as well as in ight pushing the river more and more towards the left bank, ereby increasing the sinuosity of the meander. The apex of the ander, therefore, moved in the downstream direction. From 1953 wards the Kanpur side of the flood plain was gradually raised by rtical accretion during floods, as had been going on in the ikunthpur-Bhairoghat area. This caused a fairly significant ope in the flood plain towards the left bank which in turn used the river to get entrenched along the left valley wall.

ect of the Railway Bridge : As mentioned in the introduction re are sharp changes in flow direction near road and railway dges. These sharp changes caused excessive loss of stream er which is evident from a number of large shoals in the inity of the two bridges. In fact, several spans of the

bridges on the left have been so badly silted up that people have occupied them for temporary residence. These shoals have further pushed the river to the left, with the result that severe erosion has taken place in a huge circular arc from Shankarpur to Gangaghat.

Due to rigid control of the railway bridge in the downstream, there has been squeezing of the meander and thereby increase in the meander width between Fatehpur and the railway bridge.

The probable cause of erratic meander shift of the Ganga river at Kanpur according to Hedge etal. [1989] is due to (i) highly irregular shape of the valley in the area which caused development of the flood plain predominantly on one side of river; (ii) flood plain transformation brought about by the greater flood of 1924; and (iii) the location of railway and road bridges on the extreme right side of the flood plain.

3.3 HYDROLOGICAL ANALYSIS OF STREAMFLOW DATA

For a model study of river instability and plan form change one needs to know the average flood and maximum flood hydrographs. In order to achieve this, some flow data collected from various sources are analysed. Ten-daily average discharge data of 28 years and maximum design discharge for barrage were available. Time series graphs have been drawn for maximum floods of each year and for lean period flow in each year for a period of 28 years as shown in Figures 3.3(a) and 3.3(b). The first figure shows the time series of annual peak flow. From this time series it can be seen that maximum floods of magnitude around 9000 m^3/sec

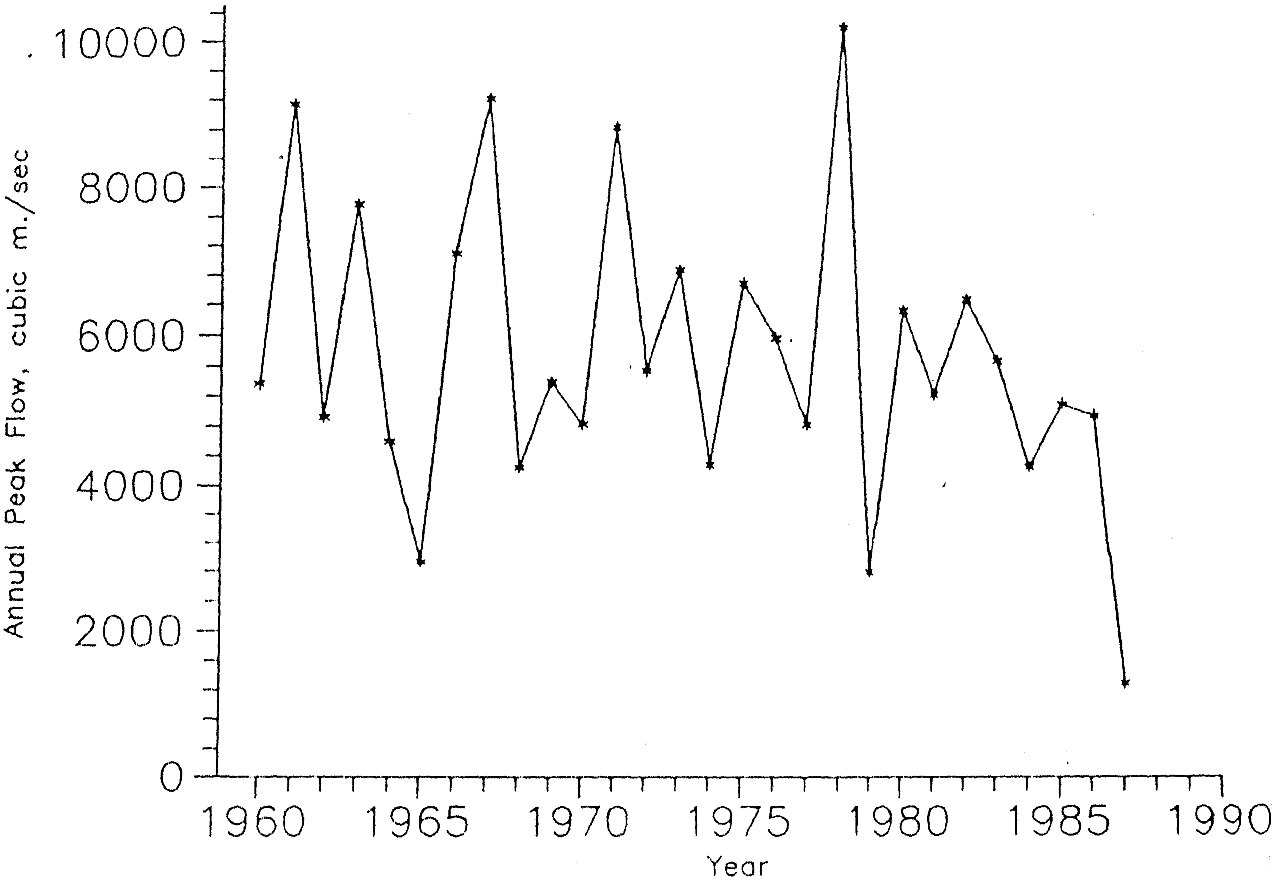
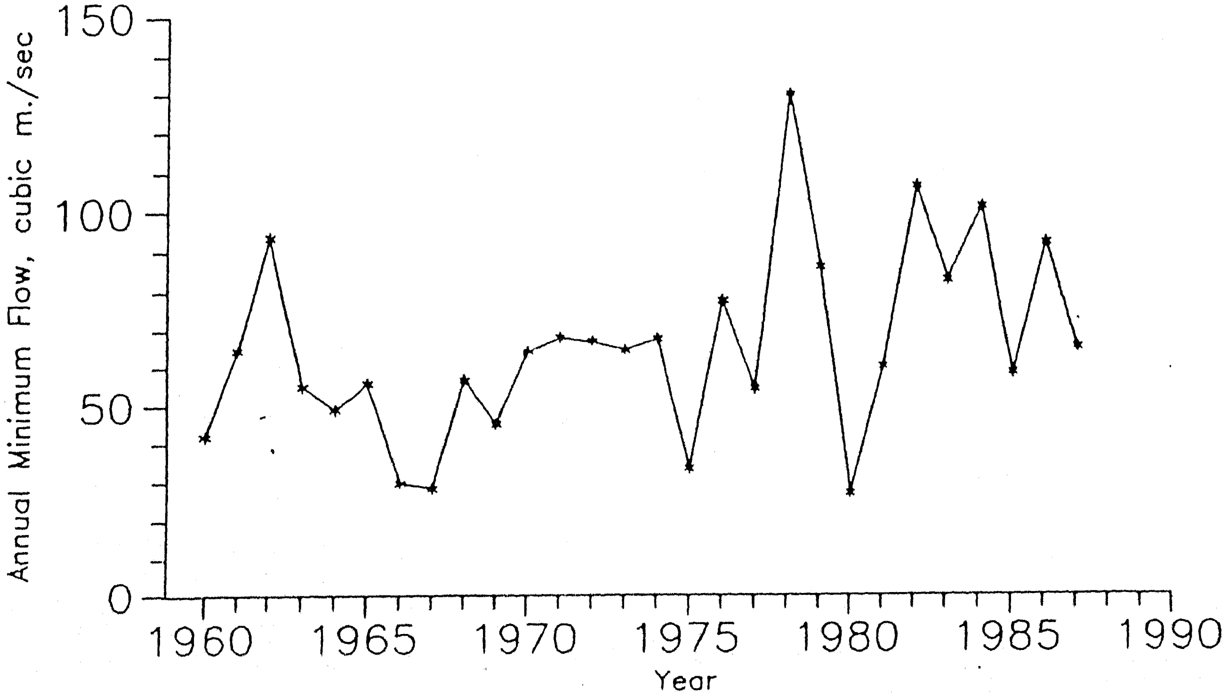


Figure 3.3(a) Time Series of Annual Maximum Discharges



occurred in four years in 1961, 67, 71 and 78. But the highest was in 1978, around 10300 m^3/sec. The second figure shows the time series of annual lean period flow. The lowest flow was in the year 1980 of magnitude around 26.0 m^3/sec.

Ten-daily average discharge data have been used for the computation of the 28 year average flow hydrograph. The average flow hydrograph and flood flow hydrograph of 1978 have been drawn as shown in Figures 3.4(a) and 3.4(b). These two hydrographs have been used in the model. The first hydrograph has been used for training the river, and the second hydrograph has been used for checking the stability of the river course.

The annual peak flow data has been used to compute the return period, T (inverse of frequency of occurrence) of flood discharge. The annual flood frequency data are found to approximately fit a Gumbel (Extreme Value Type I) distribution as shown in Figure 3.5.

The parameters for the Gumbel distribution curve are as follows

$$\bar{x} = 5746.94 \ m^3/sec.$$

$$\sigma = 2028.99 \ m^3/sec.$$

$$\text{Reduced variate } y = \frac{x - 4833.81}{1582}$$

$$\text{Cumulative probability, } F(x) = \exp\left[-\exp(-y) \right]$$

$$\text{Exceedence probability } \mathbf{P} = \frac{1}{T} = 1 - F(x)$$

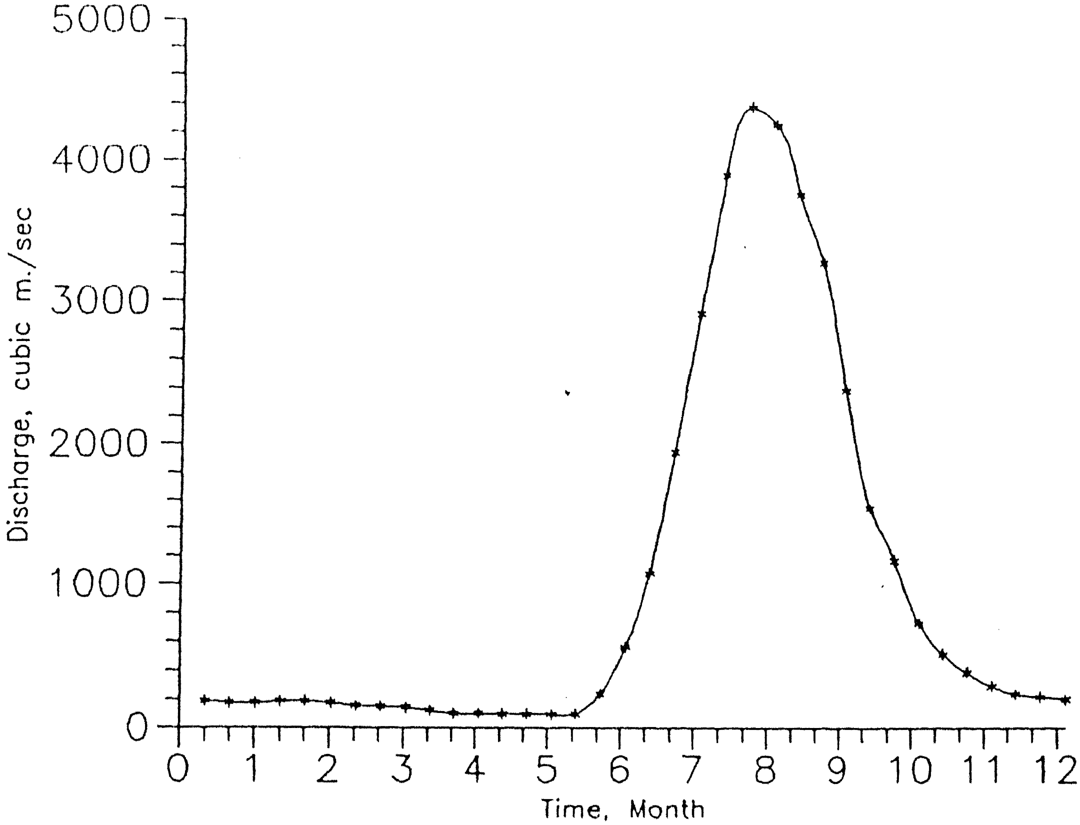


Figure 3.4 (a) Average Annual Flow Hydrograph of 28 Years

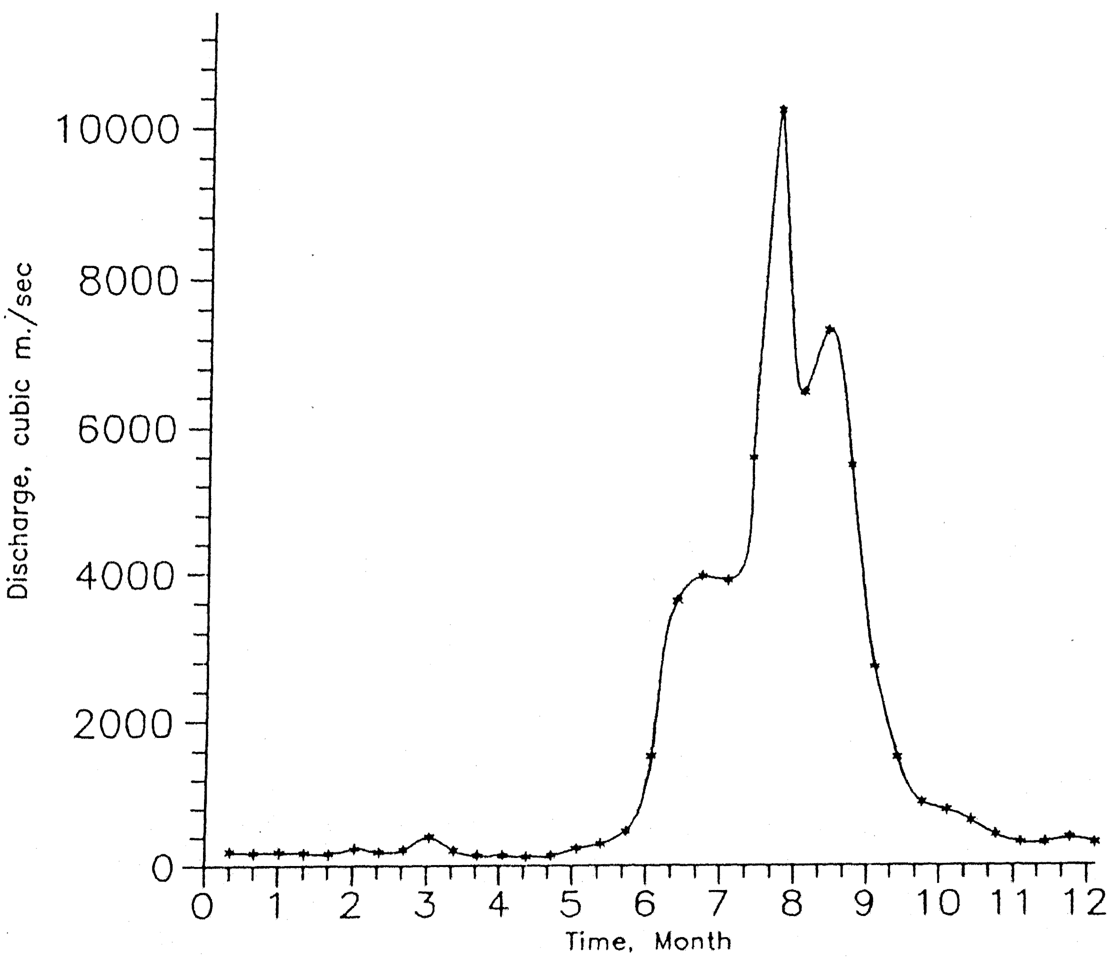


Figure 3.4 (b) Flow Hydrograph of Ganga River in 1978

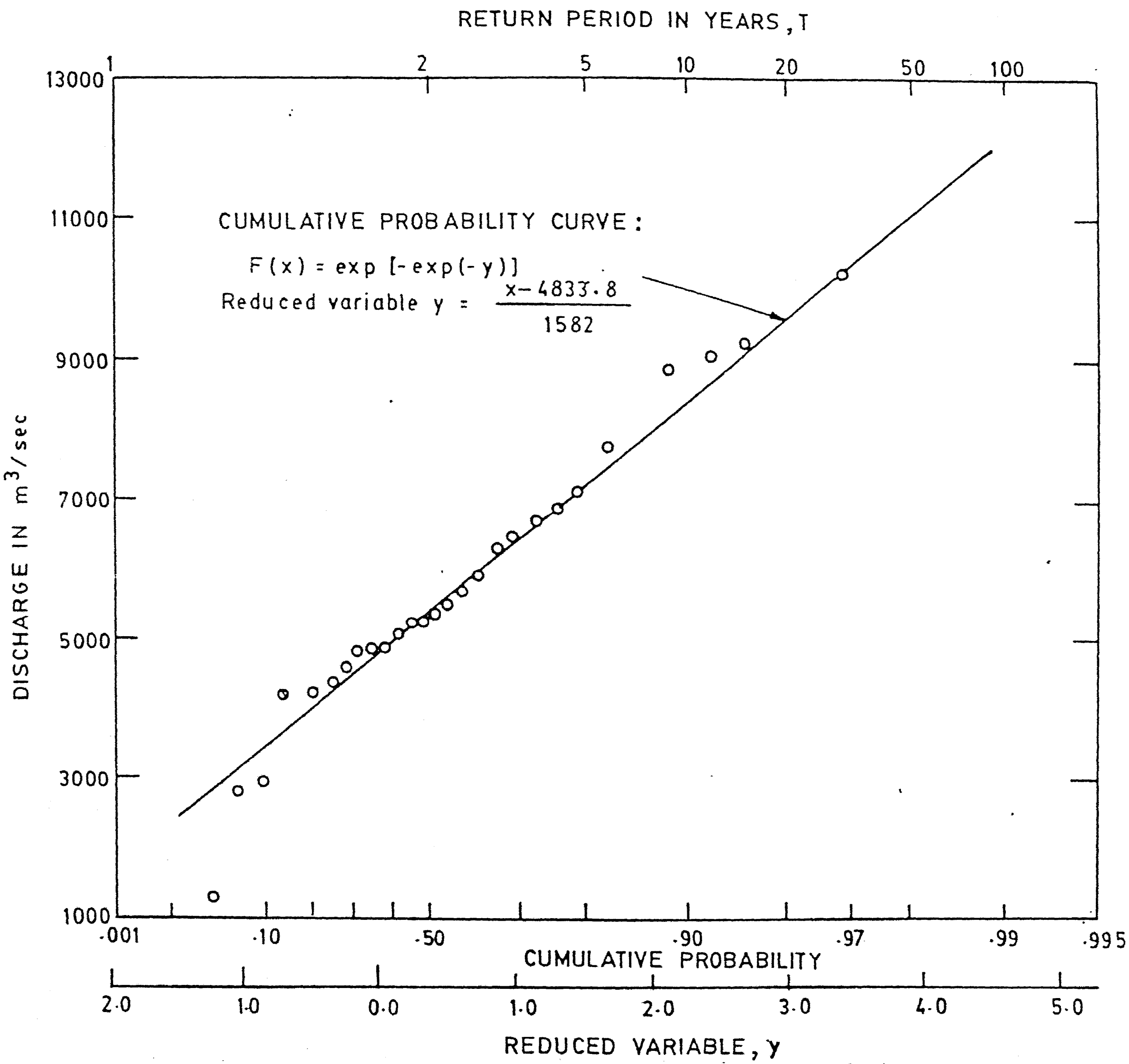


FIGURE 3.5 FLOOD PROBABILITY ANALYSIS OF GUMBEL'S

CHAPTER IV

DATA ACQUISITION AND EXPERIMENTAL DESIGN

4.1 FIELD OBSERVATION

Field trips were made a number of times to collect relevant river bed data and to note the path of flow, bed configurations and bed vegetations. A detailed field observation of the flow path, bed configurations and bed vegetation was carried out as first phase of investigation during the lean summer months.

The first field trip was to the intake structure of water works at Bhairoghat situated on the right bank of Kanpur. The Officer Incharge of water intake structures informed that the requirement of water for water works was about 10 m^3/sec per day and that amount of water was not available in lean seasons. This was due to shift of main flow current towards Unnao side. An unlined channel dug to convey water from the river to the intake structure had width about 30m at top, depth about 5m in centre, and length of about 6 Km. Dredging of the canal was in progress to keep the capacity of the canal at required level. The expenditure for dredging of the canal was of the order of Rs. 1.0 lakh per month.

Walking along the canal, one could see heaps of dredged sand on either side. That gave indication of the quantity of silt removed. Green vegetables were grown on the Kanpur side of the canal. Water was supplied to vegetable gardens from the canal by earthen pots at different places along the canal, thus damaging

the bank and causing silting in canal.

The second visit was to Bithur. Near Bithur the river divided into two streams by making a big island in between. But only a small quantity of water was flowing along the right bank and the rest of the water was flowing along the left bank. The farmers grew green vegetables on that island, and they had made a temporary bridge on the river to connect both banks.

The third visit was to Jal-Sansthan, Kanpur. With the courtesy of Jal-Sansthan sufficient information such as river maps, topographical data and cross sectional details of the river Ganga were collected.

The fourth visit was to Bithur for collection of sand samples. Sand samples across the width and also from the banks and island were collected. The locations of sand sampling at Bithur is shown in Figure 4.1.

The fifth visit was again to Bhairoghat area. There is a big island between Bhairoghat and Unnao side bank approximately 10 Km long and 4 Km wide. There are five villages on this island. Given the soil fertility the main productive activity of these villagers were agriculture and husbandry (milk farming). Villagers informed us that during high floods they all shift to Kanpur city temporarily and come back again after receding of the flood. Nine bed samples at Bhairoghat across the width were collected, locations of sand sampling near Bhairoghat area as shown in Figure 4.1. Sieve analysis was carried out to know the size distribution and properties of bed materials.

The sixth trip was to the Kanpur-Lucknow road and

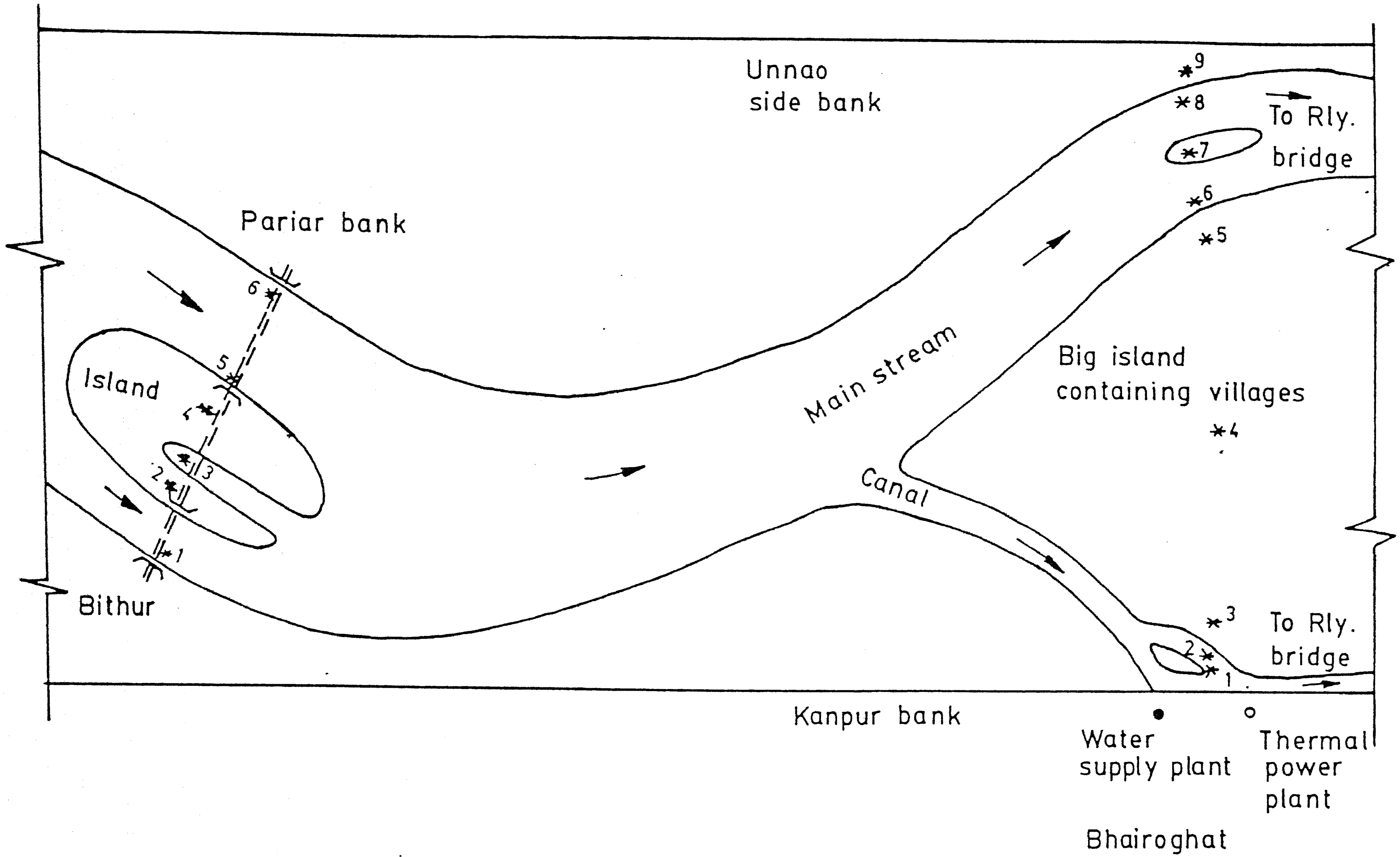


FIG. 4.1 SCHEMATIC OF RIVER GANGA BETWEEN BITHUR AND KANPUR

railway bridges. It was observed that near the left side guide bank, a big scour hole had occurred. The flow coming along the left bank curved steeply right skirting round the guide bank, then turned to the left as it approached the right bank under bridges. Huge amount of sediment had deposited along the left bank side below the bridge. On this fertile deposition again people were growing green vegetables. An office of the Central Water Commission is situated in Champapur at Unnao side of bridge. A visit to the office to obtain river data was not of much use.

4.2 BED MATERIAL DETAILS

Sediment samples scooped from river bed was kept in separate polythene bags labelling them serially. At some sections these samples were collected below the water surface and at some sections on dry bar in the river bed. Siev analysis was carried out for each location's samples to obtain the grain size distributions.

Sedment sampling near Bithur : The locations of sand sampling are shown in Figure 4.1. Sieve analysis data are presented in Figures 4.2(a) to (f). It is seen from the graphs of Figure 4.2 that the alluvial sand is more or less uniformly graded at a spot but median size varies across the section. Samples 1, 5 and 6 collected from the bed of flowing water have more or less the same median size. Samples 2 and 4 collected from island and 3 from stagnated pool bed have more or less the same median size. The former samples which were collected under running stream have larger median size than those collected on the islands.

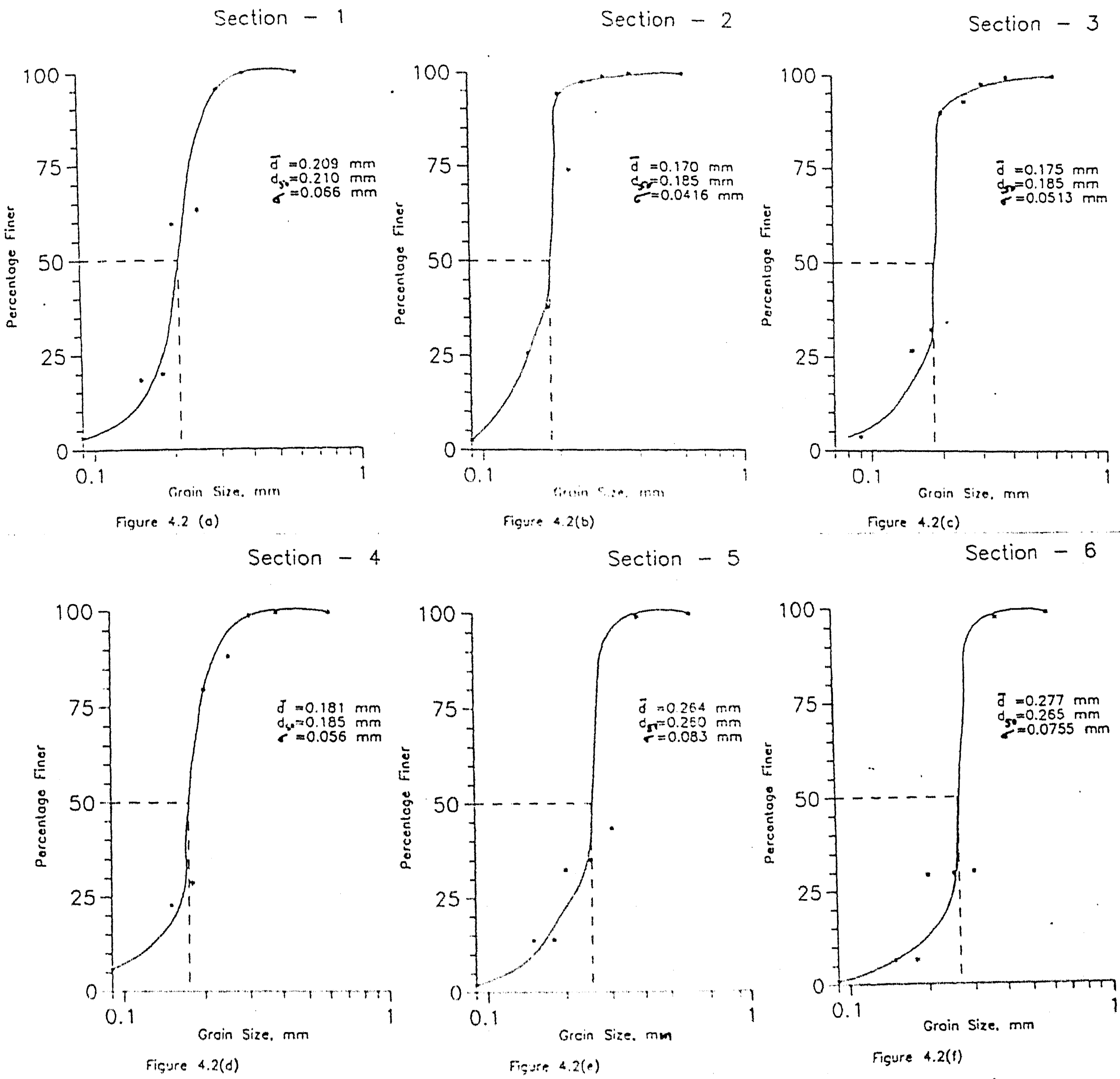


FIGURE 4.2(a-f) BED GRAIN SIZE DISTRIBUTION AT BITHUR.

For samples collected from the bed under flowing water the standard deviation was larger than for those samples collected from island.

Sediment sampling near Bhairoghat : Nine samples were collected, their locations are indicated in Figure 4.1, and sieve analysis data are presented in Figures 4.3(a) to (i). The graph show that the samples which were collected from the bed under flowing water have larger median sizes than those collected from the island, in conformity with the observation for Bithur samples. Samples 4 and 5 have been collected from the big stable island on which villages are situated. The median size of these samples are smaller than others and with higher standard deviation for sample 4, but lower standard deviation for sample 5.

The grain size distribution of bed material sampled in the lean period indicates that material under flowing water is relatively coarser than that under stagnant water or on the exposed bars or islands. This is probably because the flood flows during the monsoon season which inundates the bars and stagnant pools carry a lot of fine, suspended sand and silt. As the flow subsides the fine material settles on the bed. The flow during the remaining period of the year is relatively free of suspended material, and it gradually washes out most of the fine material from the bed over which it flows. Thus the bed material under lean period flow tends to be composed of more uniform, relatively coarser sand, whereas the material on islands and under standing water tends to be relatively non-uniform and with more fine sand. The process may be further accentuated by fine sand, and organic

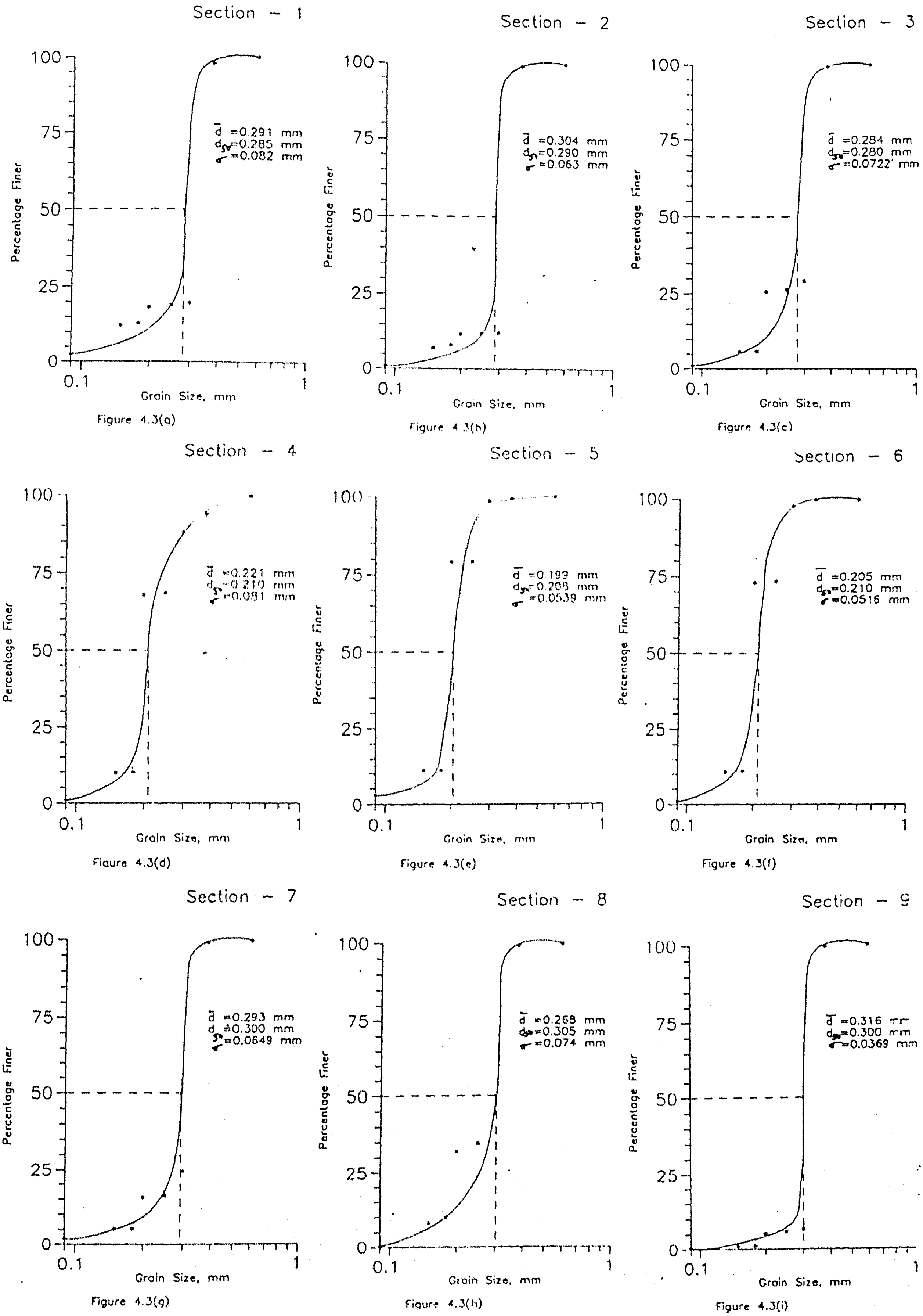


FIGURE 4.3(a-i) BED GRAIN SIZE DISTRIBUTION AT BHAIROGHAT.

materials deposited by wind and overland flow.

4.3 EXPERIMENTAL SET-UP

A rectangular steel tank of 1.1m width, 0.5 m depth and 3.5m length was used for the experiments. The whole length of tank has been divided into three parts, first and last parts having length of 25 cm and middle one with 3.0m as shown in Figure 4.4. The first part of tank has been used as inlet to the model. The last part of the modeling tank is used as sediment trap. Water was supplied from a constant level overhead tank, through a 7.62 cm dia pipe. Water from the tank was flown into a channel having a V-notch fitted for discharge measurements at the end of the channel. A point gauge was used to record the head at the V-notch and another movable point gauge was used to record the water and bed levels on the model. In the middle 3.0m length, alluvial sand collected from River Ganga was filled up to height of 30cm as bed material of the model river.

4.4 DETAILS OF MODEL

It is difficult to simulate the form of the river banks, because of the complexity of the bank sediment properties (soil cohesion). Since the prototype banks are steep and stable, it was decided to construct banks from non-erodible material by using cement with sand in 1:16 proportion. For this reason, only the model river bed was composed of erodible alluvial sand. In the present study the bed was mobile for certain flow conditions.

The length scale number lr was fixed according to

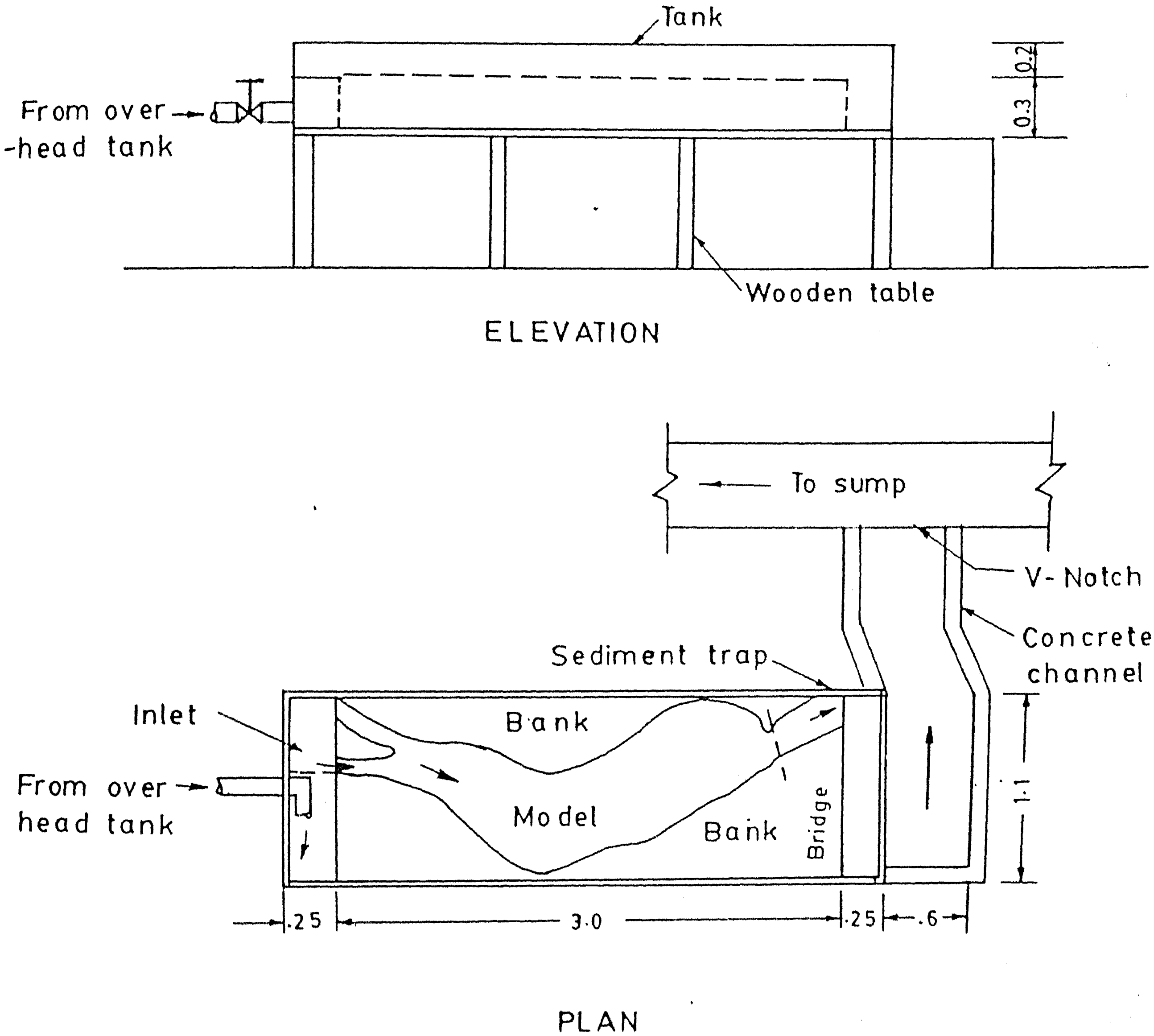


FIGURE 4.4 DETAILS OF EXPERIMENTAL SET UP.

the maximum space available for modeling. Length of 11 cm in model represented 1 Km in prototype. The vertical scale was obtained by measuring bed slope of model and corresponding slope with prototype. Same alluvial sand of the river bed has been used in the model.

The tank was filled by alluvial sand upto 30 cm depth in the middle part and water was applied for settling the sand. After leveling the sand the plan form of river Ganga shown in Figure 3.1 for 1982 was marked on the sand. Mouldable G.I. sheets were lined along the bank giving steep side slope. A wet mixture of cement and sand in ratio 1:16 was placed behind the G.T. sheets. After setting of the cement sand mixture, the G.I. sheets were removed to provide smooth-shaped, firm banks. Interior details like islands and flow paths were made with alluvial sand, according to the 1982 survey map.

4.5 MODEL SCALE

The model scales have been computed from the relations for mobile sediment beds. Since the same alluvial sand was used in model river bed so grain scale numbers $d_r = \frac{d_n}{d_m} = 1$. It was assumed that kinematic viscosity and the specific weight of water was same for mode and prototype.

To maintain the same grain Reynolds number in model and prototype

$$Re_{*r} = \frac{h_r d_r}{(l_r)^{1/2}} = 1 \qquad (4.1)$$

From the grain froude criterion

$$Fr_{*r} = \frac{h_r^2}{\Delta\rho_r d_r \, l_r} = 1 \qquad (4.2)$$

Since $\Delta\rho_r = 1$, $d_r = 1$, both the above criteria give the relation

$$h_r = l_r^{1/2} . \qquad (4.3)$$

For distorted model the Vertical scale was determined from

$$\frac{h_r}{l_r} = S_r \;, \qquad h_r = l_r . S_r \qquad (4.4)$$

and discharge scale, $Q_r = h_r^{3/2} \; l_r$ (4.5)

Time scale of the model is obtained from the Froude criterion

$$\frac{V_r^{\;2}}{g_r h_r} = 1 \;;\; V_r = h_r^{1/2} = \frac{l_r}{t_r}$$

$$t_r = \frac{l_r}{h_r^{1/2}} \qquad (4.6)$$

Using the above equations the following scales were obtained for modeling the river :

Table 4.1

Variable	Prototype value	Model Value	Scale
Length[1]	27.3 Km	3.0 m	9090
Slope[2]	0.000175	0.0123	0.0143
Depth	-	-	130
Discharge[3]	$4800 m^3/sec$	$0.0003579 m^3/sec$	1.341×10^7
Time	10 days	18.0 minutes	799

N.B : 1. River stretch corresponding to model reach.

2. Mean river slope along valley.

3. Maximum average flood discharge.

4.6 EXPERIMENTAL PROCEDURE

Water was fed very slowly in the tank till it matched the lean period flow. The discharge was increased in steps as per the time interval and discharge intensity indicated in the hydrograph. Water surface level and bed level near the guide bank of the railway and road bridges was measured before changing discharge to the next step. Thus the discharge in the model was varied according to the hydrograph. After attaining the average lean period flow, the bed profile was measured at various cross-sections. These bed profiles were used for drawing contours of bed surface, indicating the bars, islands, and other morphological changes. Hand feeding of sand was carried out at the inlet when simulating flood flows. During lean period flow sediment was not fed to the model.

The contour of bed surface was drawn at the end of each flood hydrograph. The flood hydrograph used for the study, and the level of scoured bed and water surface recorded near guide bank at the end of each step of flow change, were plotted along with the contour maps.

CHAPTER V

EXPERIMENTAL STUDY OF TRAINING THE RIVER REACH

5.1 INTRODUCTION

The aim of the present investigation is to reduce scour around the guide bunk of railway bridge situated on Unnao side, and to make flow available during lean period near the water intake structures situated on the right bank near Bhairoghat. Both these problems can be solved by shifting the river main current course along the right bank from upstream of Bhairoghat to railway bridge. This, in fact, was the guiding principle of the present experiments.

In simulating floods in the following experiments, one limitation faced was the lack of sediment transport data, that is bed load and suspended load carried by the flow. Hence as a rough approximation bed material was hand fed at the upstream (Bithur) end of the model with an attempt to balance it with the sediment outflow at the silt tank downstream. Average temperature of water was near about $30^{\circ}C$.

A summary of the relevant parameters and the results of the experiments are given in Table 5.1 at this end of the chapter.

5.2 SIMULATION OF THE EXISTING RIVER COURSE

The model bed was prepared with islands, shoals and water course according to the planform given by 1982 survey map as indicated in Figure 5.1. The lean period flow was let first to test the flow course. The flood hydrograph corresponding to the

LIGAND (5.1 — 5.9)
- Islands or Bars
- Banks
- Lean period flow path
- Spur array
- Numerical figs. indicated bed level above ref. datum
- * Champapur

Model scale :
$l_r = 9090$
$h_r = 130$
$t_r = 799$
$Q_r = 1.341 \times 10^7$

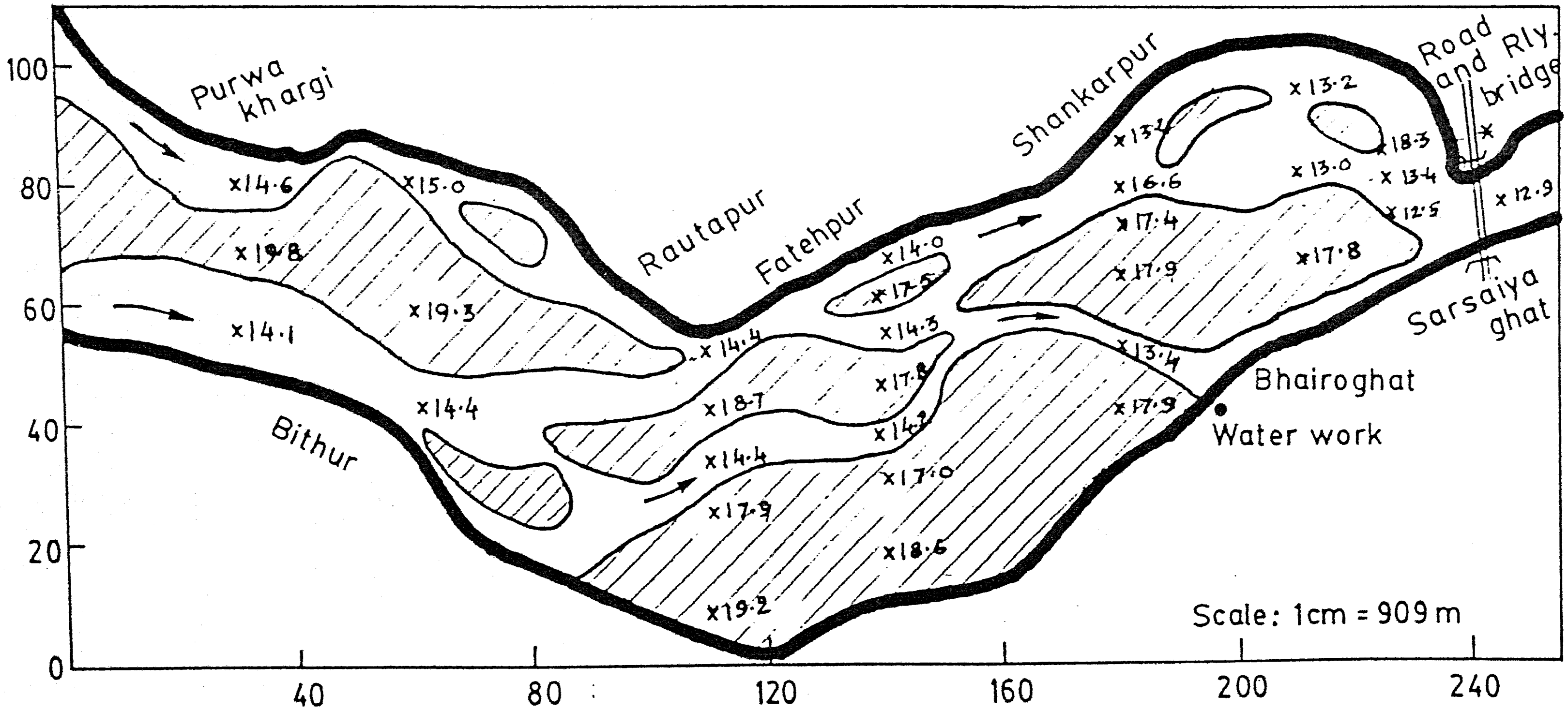


FIG. 5.1 PLAN FORM OF RIVER GANGA ACCORDING TO 1982 SURVEY

average flood of 4800 m^3/sec, reduced to scale is flowed in time steps calculated according to the time scale. Contours of the bed surface were drawn after measurement of bed levels during the lean period. The flood hydrograph and bed and water surface levels near guide bund are plotted in Figure 5.2(a). A photo of the flow path is shown in Figure 5.2(b). The main current course was along the left bank from Shankarpur to guide bund. The scour at the guide bund was severe, of the order of 5cm in model (correspondingly 6.5m in prototype). The scour hole remained almost the same size without filling up during the lean period of flow.

The maximum flood of 10240 m^3/sec that occured in the year 1978 was simulated after remodelling the bed to the 1982 record map. The bed levels after the lean period flow, the hydrograph, and water surface level and bed level records at guide bund are plotted as shown in Figure 5.3(a). The flow pattern over the whole length and at guide bund are shown in Figure 5.3(b) and 5.3(c) respectively. The flow path adhered to the left bank from Shankarpur to road and railway bridge with a deep scour hole of 6.0cm deep in model. No flow near water intake structures during lean period was observed. The scour hole was found to get partially filled with sand to near about 1.6 cm in model during the lean period. The flow near Bithur was divided with an island in between. The divided flow reunited near Rautapur. A big island was formed near the right bank from downstream of Bithur to Sarasaiyaghat near road and railway bridge.

The design discharge of barrage 18840 m^3/sec, was

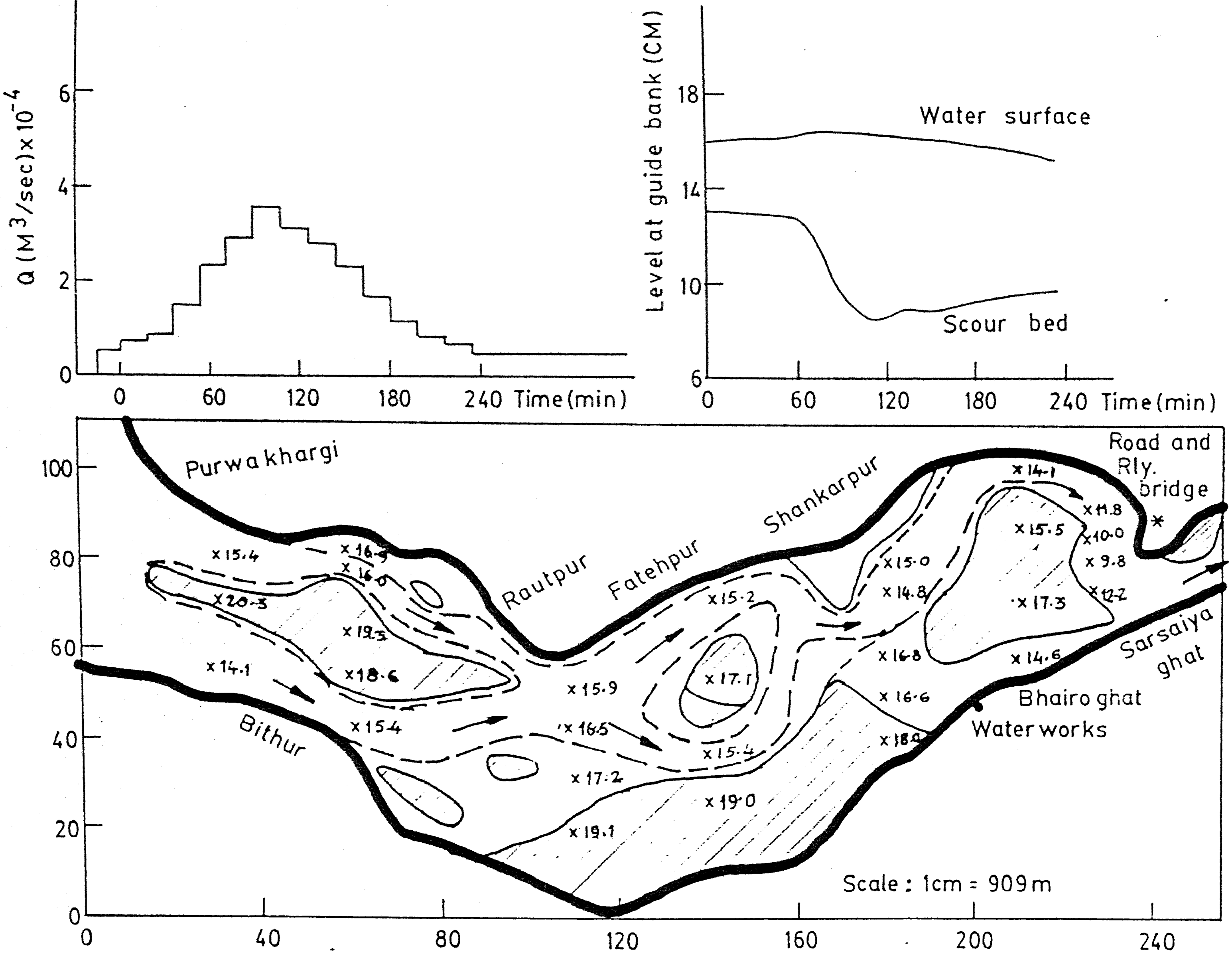


FIGURE 5.2(a) PLANFORM OF RIVER MODEL AFTER AVERAGE FLOOD
$Q = 4820\ m^3/sec$ ($Q_{MODEL} = 0.0003597\ m^3/sec$)

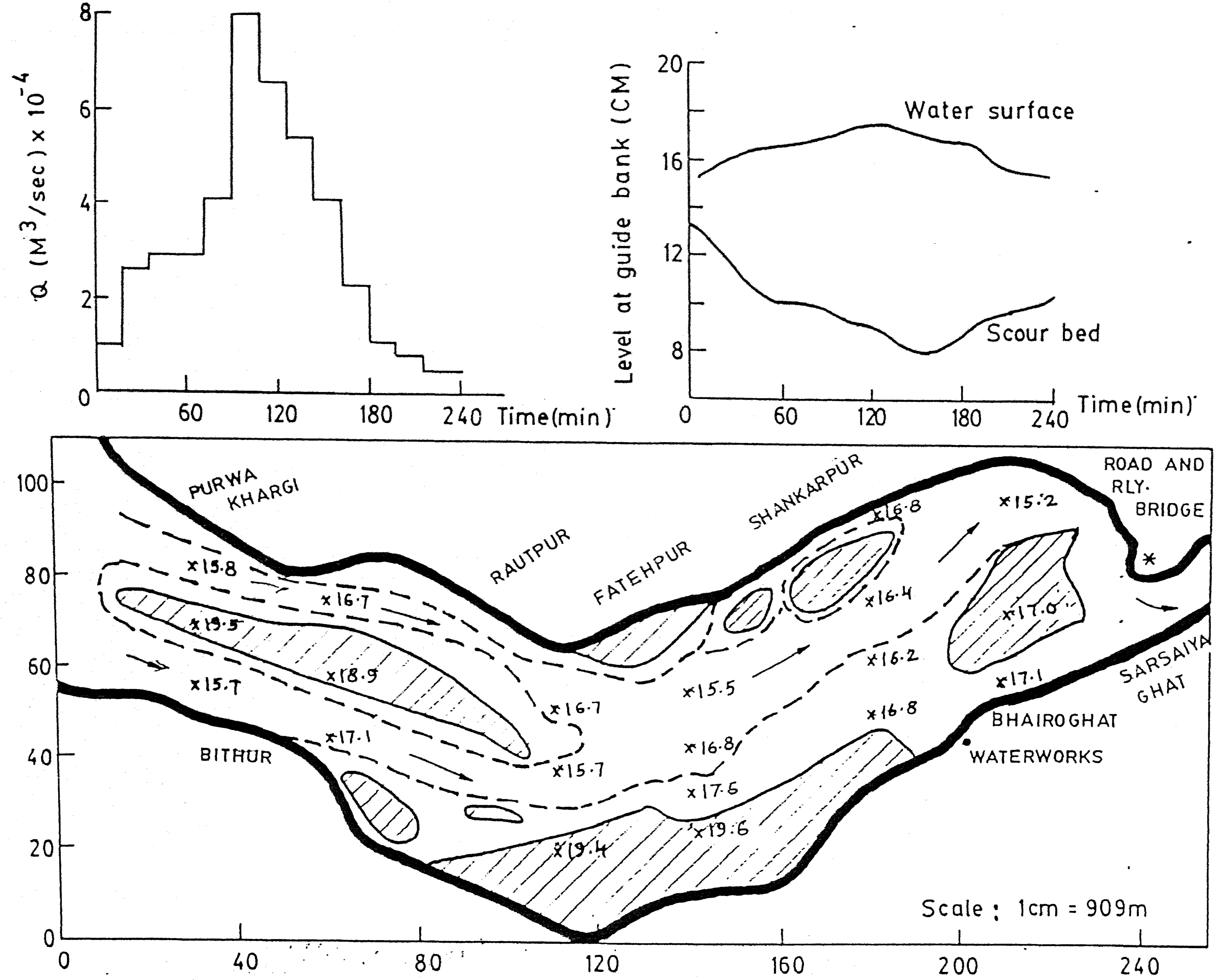


FIGURE 5.3(a) PLANFORM OF RIVER MODEL AFTER PEAK FLOOD Q_{MAX} -

Figure 5.2(b) Photo of River model showing flow path after average flood $Q = 4820\ m^3/sec$.

Figure 5.3(b) Photo of River model showing flow path after peak flood $Q_{MAX} = 10725\ m^3/sec$.

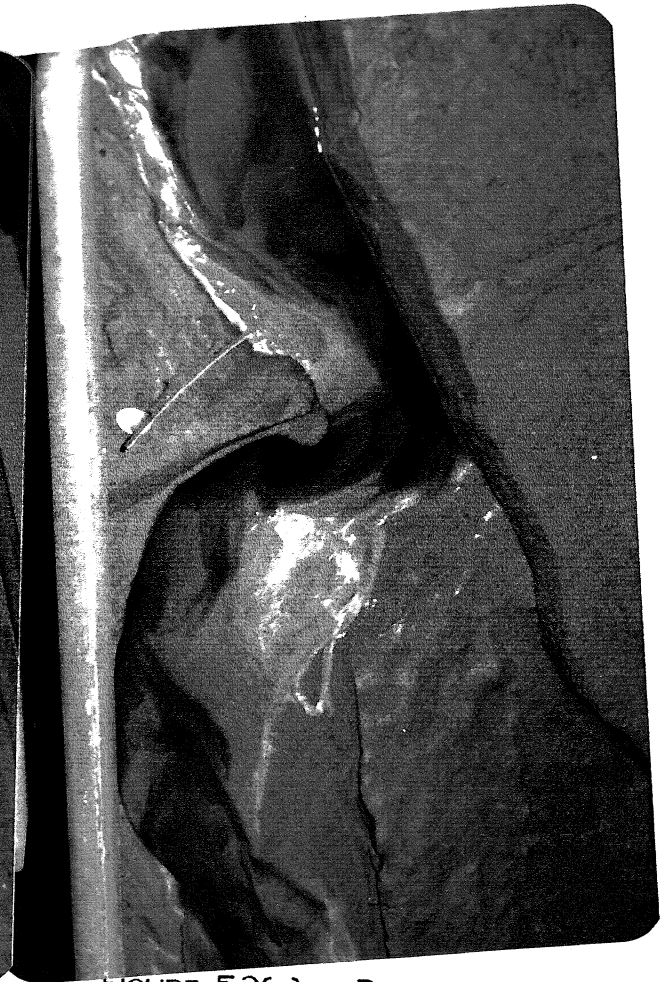


Figure 5.3(c) Photo of River model showing details of flow path at bridges.

allowed to be reached gradually after remodelling the bed to 1982 records. As the flood approached the peak value, the water course shifted from left bank to the right bank avoiding the meander from Rautapur to railway road bridge. The main flow current adhered to the right bank making water available near at the water intake structure. The scour hole near guide bund also started filling up with sand. Now, while the main current was not hitting the bridge embankment, a deep pool that had been formed all along the embankment did not get filled up with sediment. It is possible, however, that this pool may get filled up by suspended sediment in prototype. Since sediment transport in model is mainly bedload, the process of filling up of scour hole could not be observed in the model. The flow course indicated in Figures 5.4(a) and 5.4(b) should be the path of the river to achieve the aim of its training. Hence permeable spurs were fixed on the river bed as indicated in Figure 5.5.

5.3 TRAINING OF THE RIVER COURSE

The flow path, to be achieved by training is indicated in Figure 5.4a. Permeable spurs were used as training aids to achieve the desired flow course. The model spurs were copper rods of diameter 4mm and height 150 mm. They were arranged in a row with lateral spacing of 4 to 5 times the diameter. It was observed that a single row was not effective in diverting the flow and reducing the magnitude of the velocity of flow which passed through them. In order to reduce the velocity and to raise downstream bed level, a second row of spurs were contemplated.

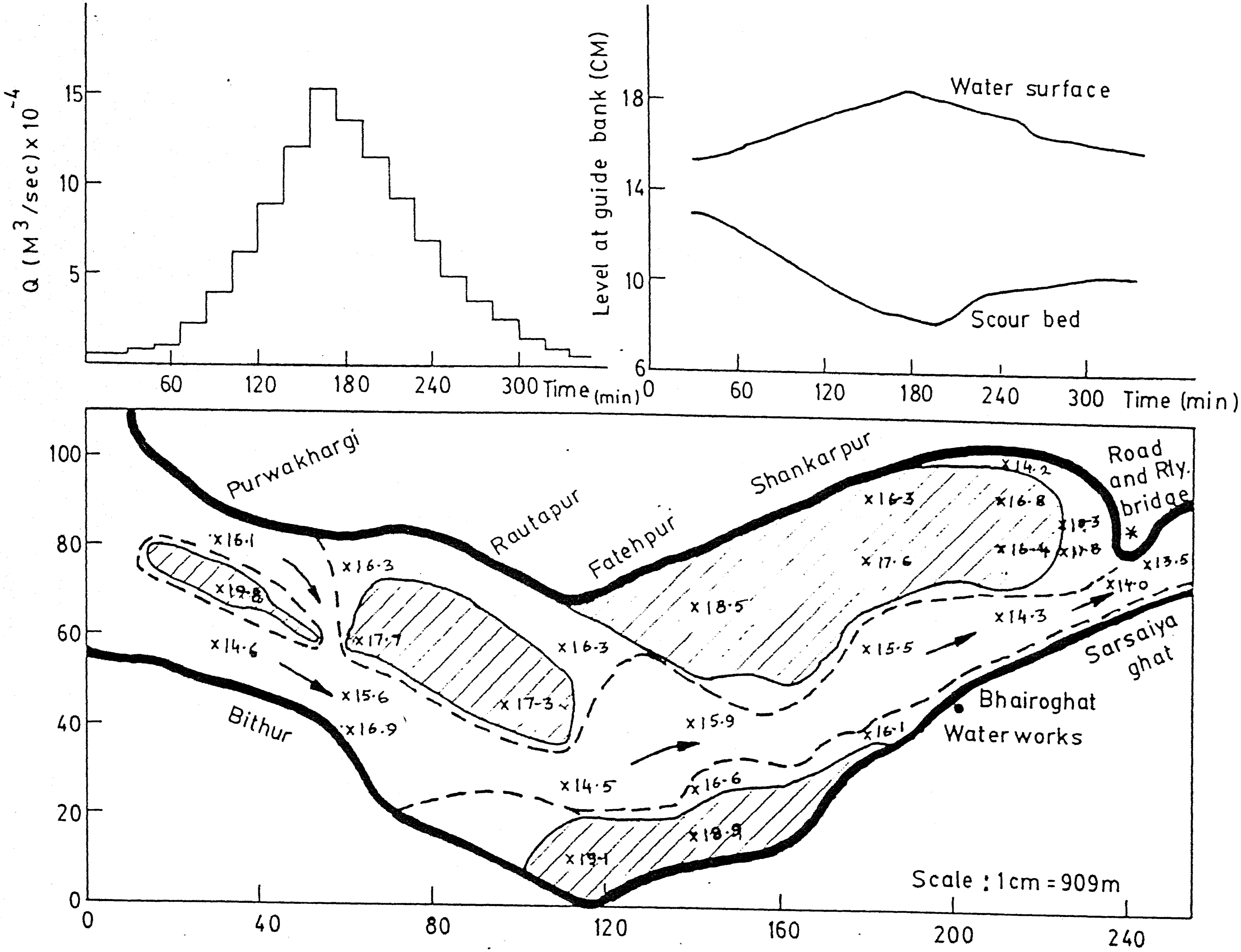


FIGURE 5.4(a) PLANFORM OF RIVER MODEL AFTER Q = 18840 M^3/SEC (Q_{MODEL} = 0.001525 M^3/SEC).

These rods were fixed in between the spacing of the first row and at a distance of 7 to 8 times diameter of rod downstream of first row. It was observed that two rows of rods arranged in staggered way were effective in diverting the flow. Figures 5.5a and 5.5b indicate the two rows of permeable spurs starting from the left bank and penetrating into the flow at an angle.

The hydrograph of average flood was tested on the flow course. After allowing the flood flow to increase and then decrease in time steps as computed, and on receding to the lean period flow the bed levels were taken. The period of maximum flow was increased to test the severity of flood on the flow path and also on the scour at guide bund. The scour depth was reduced considerably. It was observed that as the flood flow increased the guide bund was hit by main flow current. Also, a part of the flow was passing through the permeable spurs, causing a skirting round the guide bund. This flow pattern was considered as not effective. Figures 5.5 indicate the flow directions, bed levels, flood hydrograph, and bed level and water surface level at guide bund.

In order to achieve a better performance of the model, again the model was leveled according to 1982 survey map without removing the spurs. Again the average flood hydrograph was allowed to flow as indicated in Figure 5.6. While executing the flow of flood hydrograph and tracing the path of flow current by permanganate crystals, an additional row of permeable spurs near

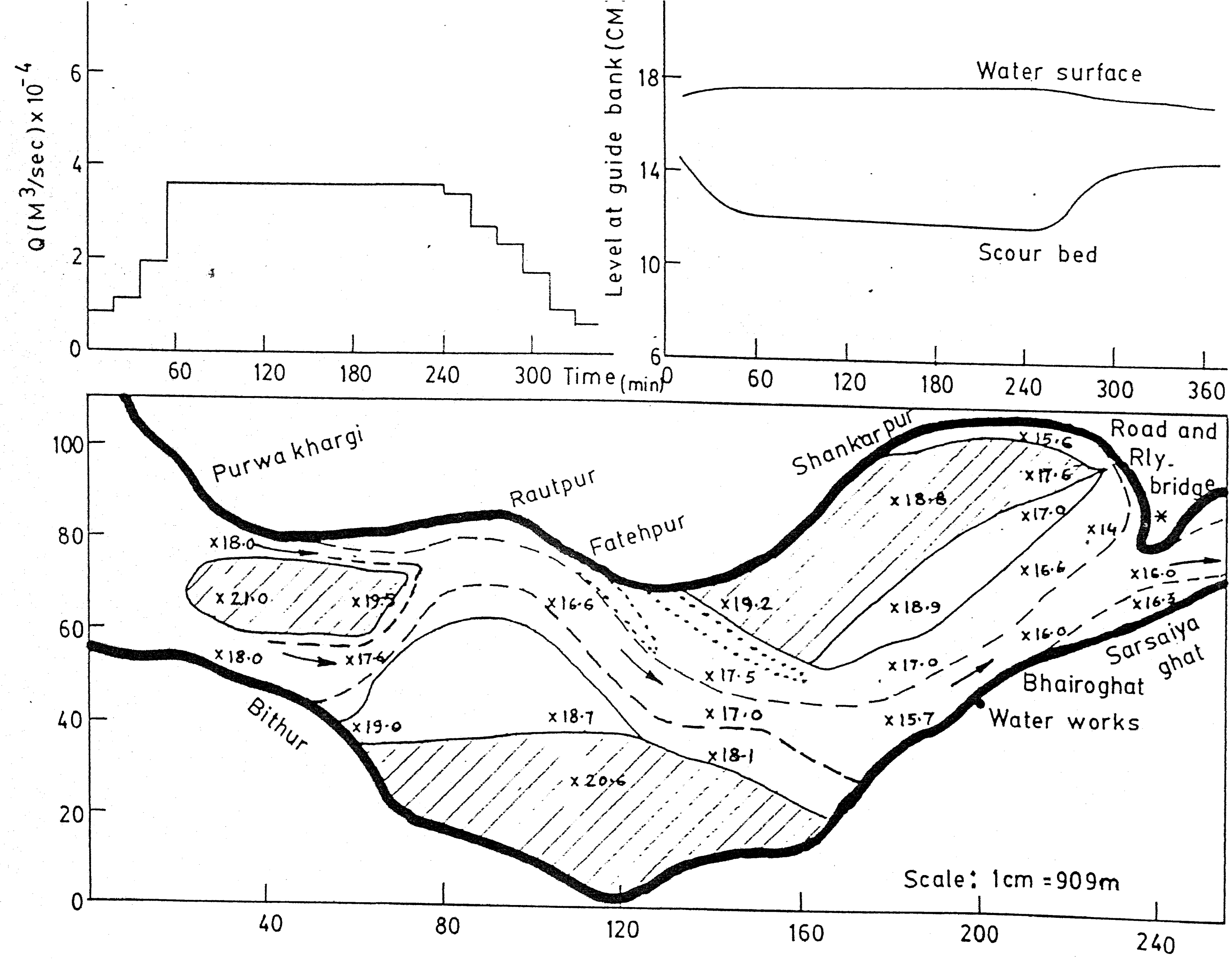


FIGURE 5.5(a) RIVER TRAINING USING PERMEABLE SPURS Q_{MAX} = 4830 M^3/SEC (Q_{MODEL} = 0.00036 M^3/SEC).

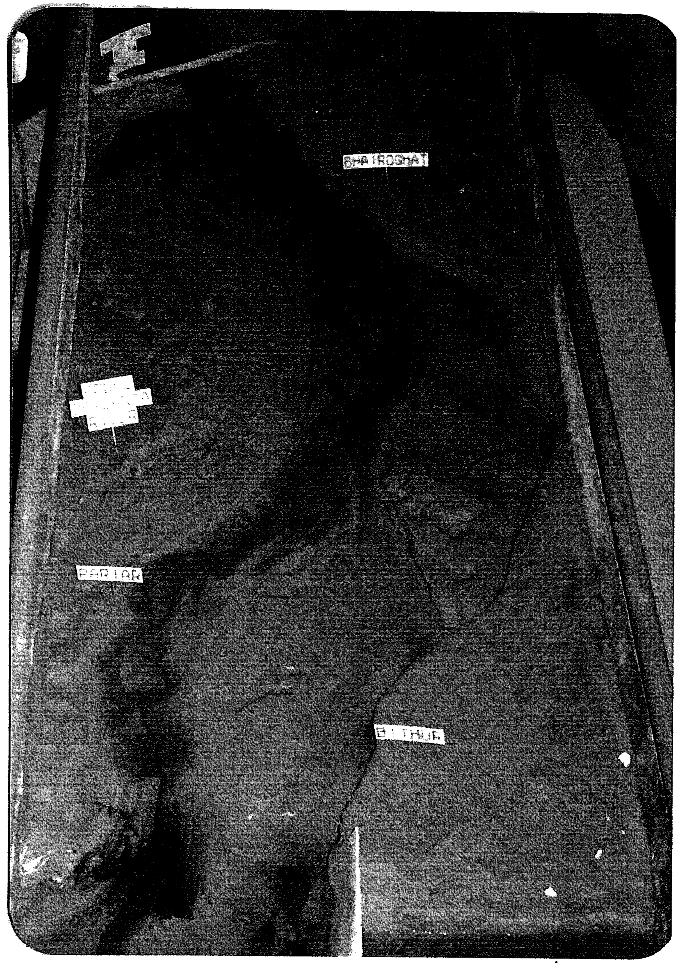


Figure 5.4(b) Photo of River model showing flow path after $Q = 18840\ m^3/sec.$

Figure 5.5(b) Photo of River training model using permeable spurs $Q_{MAX} = 4830\ m^3/sec.$

Figure 5.5, one more row of permeable spurs, that is three rows of rods, were arranged at different lengths as indicated in Figure 5.6. The scour was reduced considerably at guide bund and the performance of this arrangement was found to be satisfactory. However, it was noticed that the length of the first array of permeable spur was rather excessive.

Aiming for further reduction in the installation of spurs, the model indicated in Figure 5.7 was conceived in order to divert the water course right from Bithur. With this consideration the spurs were arranged in the way shown in Figures 5.7(a) and 5.7(b). The simulated flood was that of 1978 (10240 m^3/sec). The bed levels, flow paths, and scour details near guide bund were plotted. The flow path was along the right bank from upstream of Bhairoghat to road and railway bridges. There was a remarkable reduction in scour depth near the guide bund. Further, along the whole of left bank from upstream of Rautapur to road and railway bridges, a bar developed due to sediment deposition. This part of the island in prototype may be reclaimed for use. Along the right bank only one bar formation from downstream of Bithur to far upstream of Bhairoghat was observed. The river flow path from Bithur to the road and railway bridges was almost straight during flood, and meandering during lean period. Meandering width was also reduced considerably. Another interesting result of the above run was that the flow was brought near the water intake structure during the lean period.

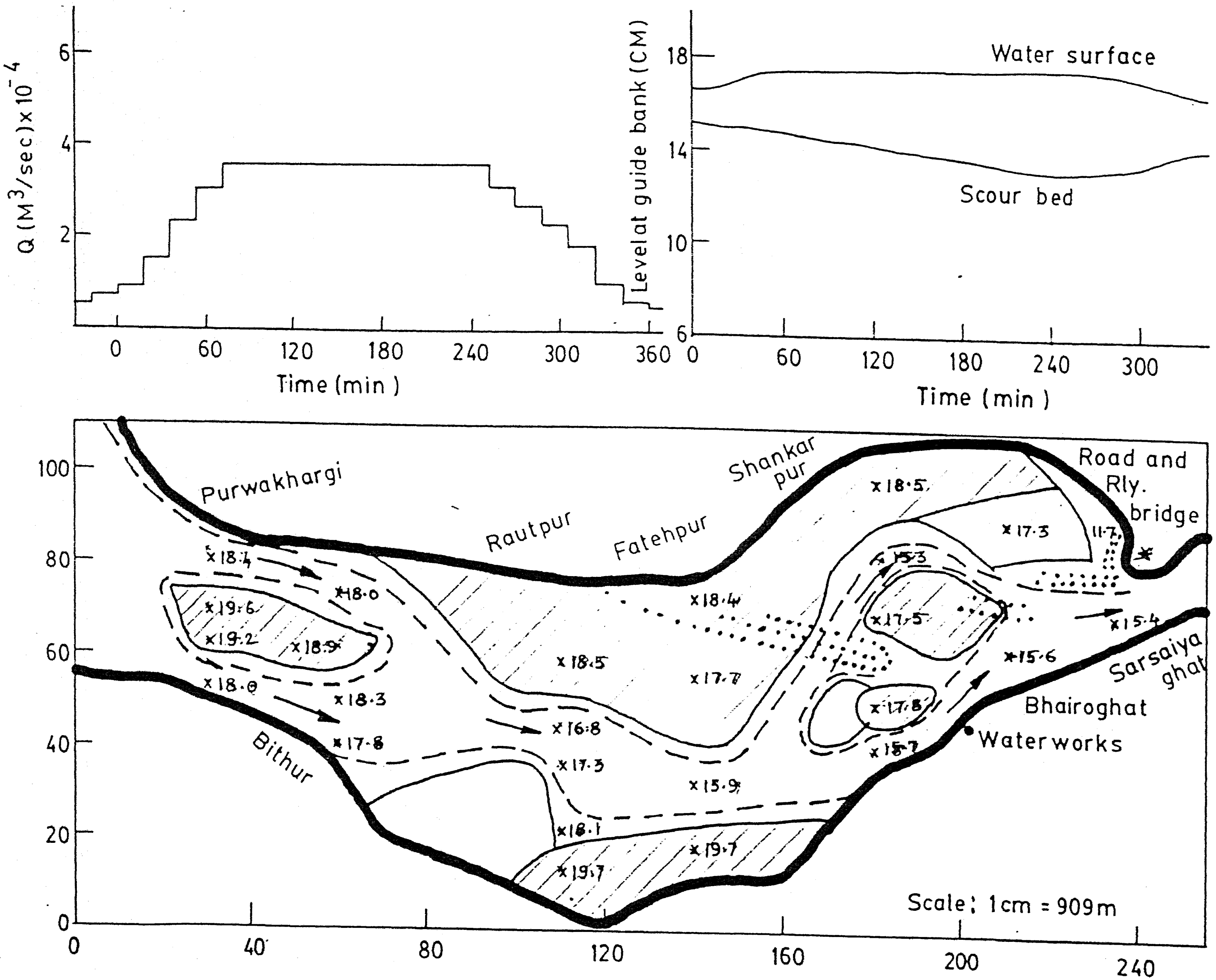


FIGURE 5.6 RIVER TRAINING USING PERMEABLE SPURS Q_{MAX} = 4830 M^3/SEC (Q_{MODEL} = 0.00036 M^3/SEC).

array was removed. The bed was modelled according to the 1982 survey map without removing the other spur arrays, and subjected to average annual flood hydrograph. The bed level, flow path, islands, shoals and scour details near guide bank and the flood hydrograph are shown in Figure 5.8(a). Figure 5.8(b) indicates the flow pattern during transition of shifting from left bank to right bank near Bhairoghat. The flow path during lean period was at the water intake structures, and all along the right bank to bridge passage. The scour depth was reduced considerably. The earthen embankment built to protect the road and railway bridge was thus completely safe from the flood attack. Further, a big bar on the left bank was formed, indicating the possibility of reclaiming this land. This configuration of permeable spurs arrangement was now simulated with the 1978 flood hydrograph.

5.4 CHECKING FOR THE 1978 FLOOD

The flood hydrograph corresponding to the 1978 flood was allowed to flow through the model river with spur arrays as indicated in Figure 5.8. After the run the bed levels, flow paths during lean period, islands, hydrograph, and bed and water surface levels at bridge guide bank were plotted as indicated in Figure 5.9. Figure 5.9 indicates that the performance of permeable spur was better in this case than for the average annual flood. The scour depth was reduced considerably, the island width on the left bank increased and the lean period flow was along the right bank, from far upstream of Bhairoghat till the road and railway bridges.

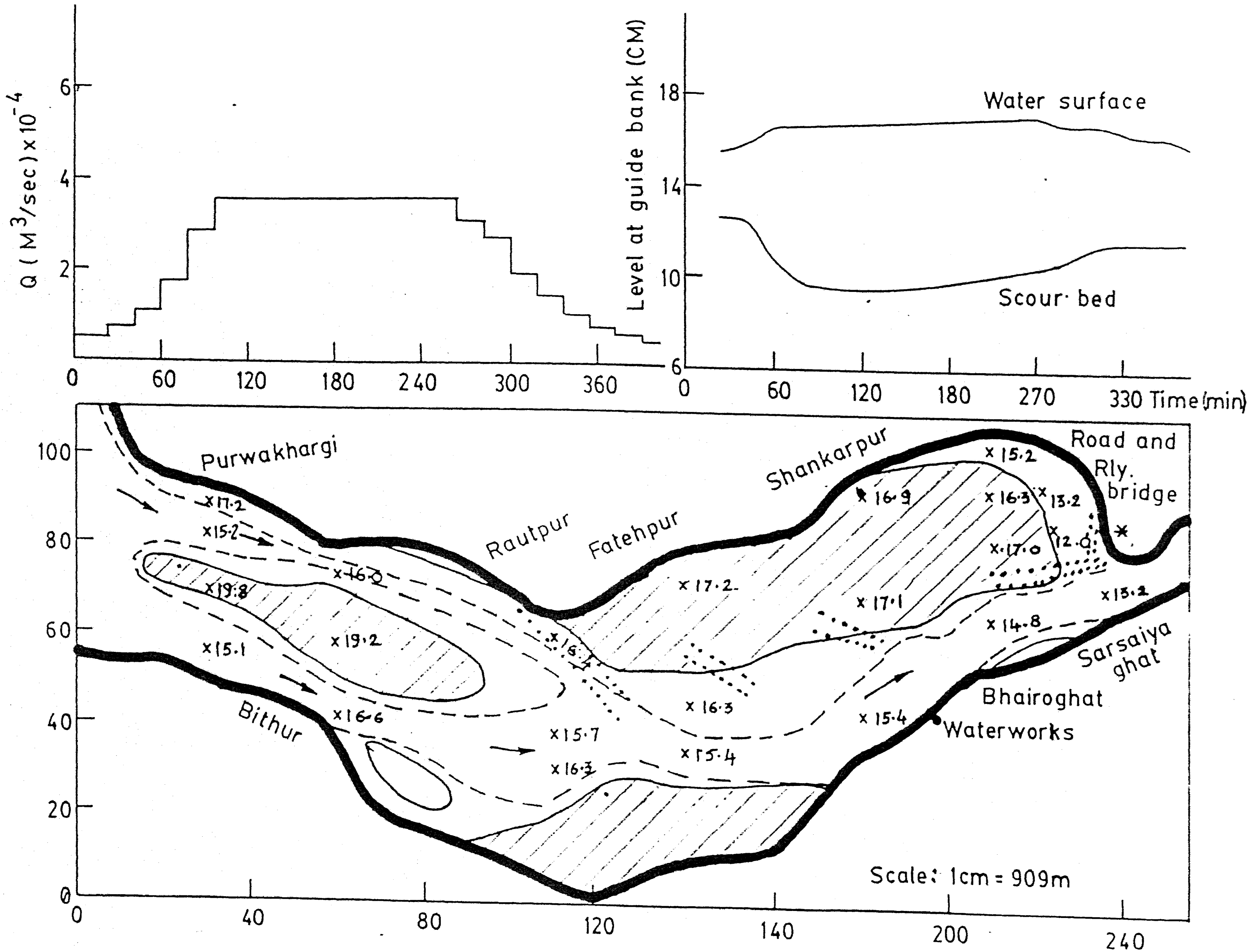


FIGURE 5.8(a) RIVER TRAINING USING PERMEABLE SPURS, Q_{MAX} = 4830 M^3/SEC (Q_{MODEL} = 0.00036 M^3/SEC).

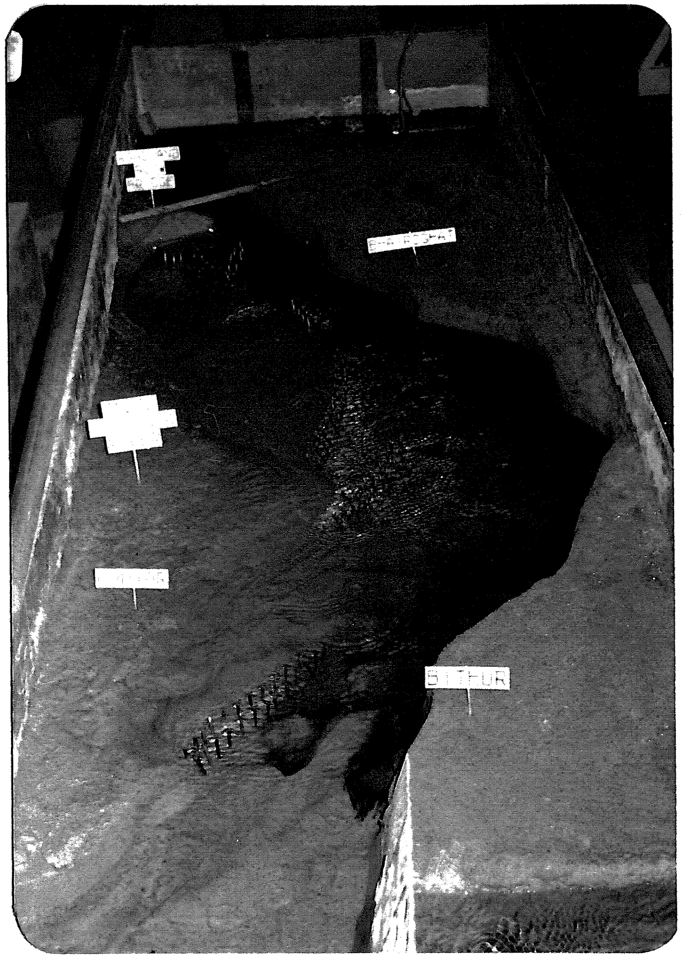


FIGURE 5.7(b) PHOTO OF RIVER TRAINING MODEL USING PERMEABLE SPURS, $Q_{MAX} = 10240\ M^3/SEC.$

FIGURE 5.8(b) PHOTO OF RIVER TRAINING MODEL USING PERMEABLE SPURS, $Q_{MAX} = 4830\ M^3/SEC.$

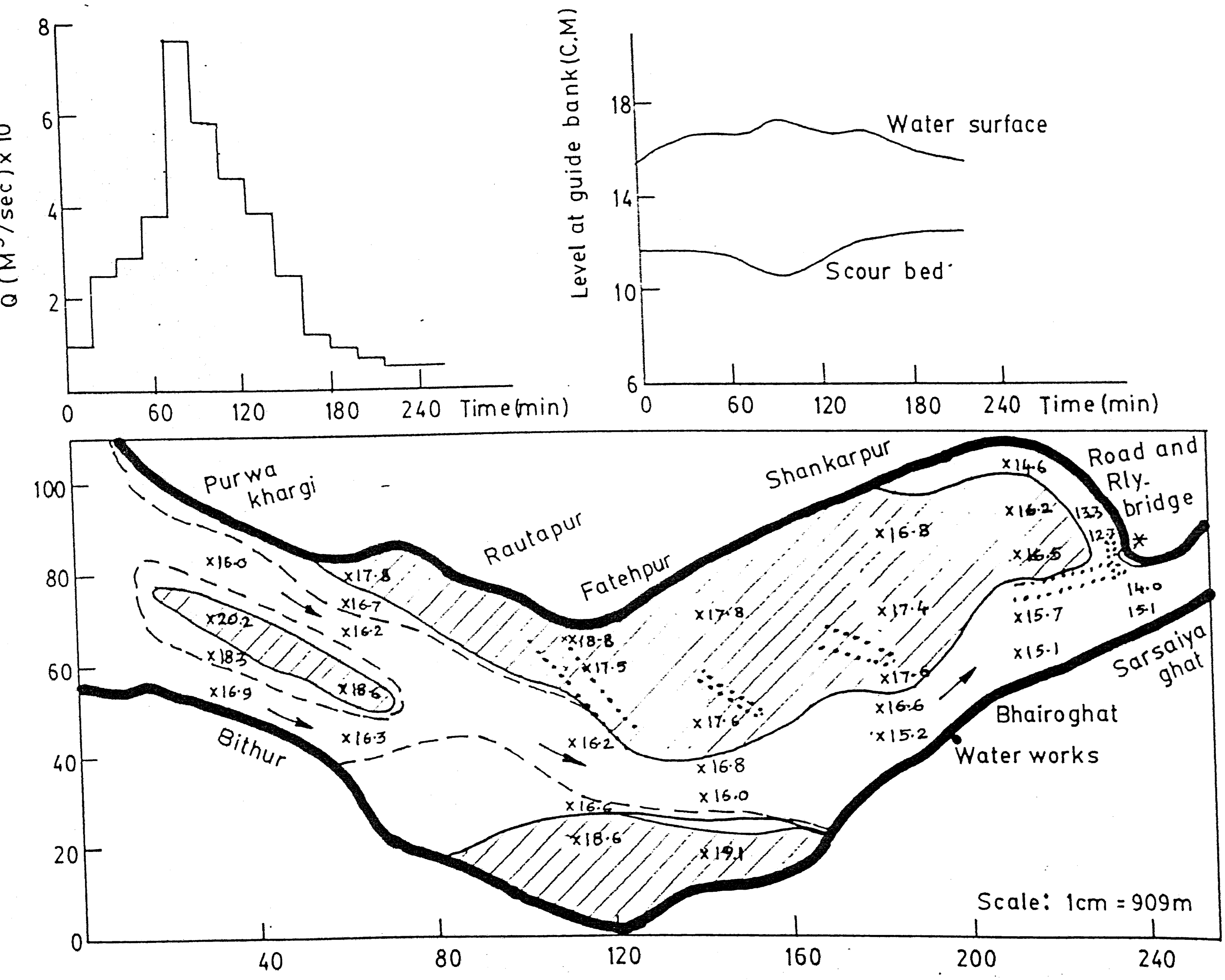


FIGURE 5.9 ARRANGEMENT OF PERMEABLE SPURS TO TRAIN THE FLOW COURSE Q_{MAX} = 10240 M^3/SEC (Q_{MODEL} = 0.000763

From the above test it was concluded that the permeable spur arrangement indicated in Figure 5.8 is adequate for training the river to achieve two objectives, namely to divert the lean period flow near the water intake structure and to reduce the current attack and scour at the guide bank provided to protect the road and railway lines at Unnao side. Table 5.1 summarizes the comparative features of different experiments conducted in this study.

Table 5.1 Summary Information of Models Tested

Model run	Flood hydrograph	Training works	Model Results	
			scour at embankment	planform and other changes
1.	Average annual flood 4820 m^3/sec	None	5.0 cm at peak flood and reduced by 1.0 cm in lean period.	Some islands washed out between Rautapur and Fatehpur and formed small bars. Flow path was along the left bank.
2	1978 flood = 10240 m^3/sec	None	6.0 cm at high flood and reduced by 1.6 cm in lean period.	Flow path divided by island at Bithur. Many shoals and bars between Fatehpur and Shankarpur and a big island formed near right bank downstrea of Bithur. Flow path comes near wate works in high flood but along left bank in lean period.
3	Design discharge of barrage = 18840 m^3/sec	None	5.0 cm and reduced by 2.5 cm in lean period.	Big island scoured from right bank and bars formed along left bank. Flow shifted to right bank in lean period also.
4.	Average annual flood = 4820 m^3/sec	Double row of spurs 4 to 5 dia c/c near left bank close to Rautapur	2.0 cm and completely reduced in lean period.	Flow was divided by island at Bithur and big bars formed behind spurs. Flow along right bank but direct hit to guide bank and embankment at left side.
5.	Average annual flood = 4820 m^3/sec	Three rows of spurs @ 4 to 5 dia c/c with additional spurs at an in front of guide bank.	1.5 cm and completely reduced in lean period.	Big sand bars formed along the left bank from Rautapur to Shankarpur; small sand bars along right bank. Flow along right bank and some flow divert towords left in lean period.

6.	1978 flood = $10240 m^3/sec$	Double row of spurs @ 4 to 5 dia c/c near left bank.	2.0 cm and completely reduced in lean period	Flow divided at Bithur and island formed down-stream of Bithur. Big sand bars along left bank from upstream of Rautapur to upstream of railway bridge.
7.	Average annual flood = $4820\ m^3/sec$	Double row of spurs @ 4 to 5 dia c/c near left bank and along the quide bank.	3.0 cm and reduced by 2.0 cm in lean period	Flow path was along the Right bank during lean period. Flow divided by island at Bithur; big sand bar formed along left bank, also along right bank. Flow completely shifted toward right bank in lean period also.
8.	1978 flood =$10240\ m^3/sec$	-do-	1.0 cm and completely filled up in lean period	Sand bars formed along whole left bank from upstream of Rautapur to upstream of railway bridge. Bars also existing at right bank. Flow along the right bank making water available at water works, round the year.

CHAPTER VI

CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

.1 CONCLUSIONS

Hydraulic modelling of River Ganga near Kanpur was carried out to achieve two objectives namely (a) to bring the flow during summer months near Bhairoghat where city water supply intake structure is situated, and (b) to reduce the severity of scour occuring at the bend near Champapur, which has an earthen embankment built to protect the railway and road bridge connection Kanpur to Lucknow. After full reconnaissance of the river reach near Kanpur and collection of flood data and bed level data from different sources, a distorted hydraulic model with horizontal scale 1 in 9090 was prepared. The average annual flood and the peak annual flood of 28 years were used for simulating the river discharge in the model. The model was tested for its ability to reproduce the existing plan form pattern of the river using the average annual flow hydrograph. The highest flood intensity used for the design of the proposed barrage by Kanpur Development Authority, indicated the flow path for which the river has to be trained.

Permeable spurs made of copper rods of diameter 4 mm spaced laterally 4 to 5 diameter apart in two rows in staggered, arrangement, with spacing between the rows of 8 diameter was adopted to train the flow path in the model. After various trials, the spur arrangement indicated in Figure 5.8 was evolved to achieve the two aims cited above. This spur arrangement was tested for the highest flood in 28 years, wherein its performance improved in comparison with the 28 years average flood hydrograph.

n both cases the lean period flow skirted the water intake works t the river's right bank, and considerably checked water velocity nd scour near the embankment. The river thalweg had a stable rofile closer to the right bank.

.2 LIMITATIONS

The main limitations of the present model are the ollowing :

(a) The horizontal scale of the model is too large and its vertical scale is also large. The ratio of horizontal to vertical scale should not exceed about 6:1 for reliable results.

(b) Materials like coal dust, which are lighter in density in comparison to alluvial sand, should be used in the model bed to simulate bed mobility with less scale distortion.

(c) The sediment transport in model is by bed load only whereas in prototype, the sediment is moved mostly in suspension. This can be achieved by changing to less dense bed material.

(d) The sediment load data of the river were not available. Efforts should be made to get these data from Central Water Commission Office situated near Champapur or from other sources.

6.3 RECOMMENDATIONS FOR FURTHER WORK:

A hydraulic model to a reasonable horizontal scale of 1 in 600 and vertical scale of 1in 100 with coal dust as the bed

ıterial should be built for detailed study. An economic ›praisal of the use of permeable spurs as river training aid in ›mparison to building the proposed barrage at Bhairoghat should ː made for appropriate selection of the one that best suits the ʌin objectives.

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APPENDIX A

A.1 DIMENSIONAL ANALYSIS OF SEDIMENT MOTION :

For studying the very complicated processes at the initiation of sediment motion and during sediment transport, where the transporting fluid and the transported sediments interact with each other, it is advantageous to consider the various factors of influence beforehand.

The specific sediment transport rate g_s, expressed as mass per unit time and unit width, depends upon the material properties of the fluid and the sediment, upon the grain diameter d of the transported material as well as upon the water depth h and the slope S of the transporting flow.

$$f(g_s, \rho_w, \nu_w, g, \rho_s, d, h, S) = 0 \qquad (1)$$

By dimensional analysis (π theorem of Vaschy), five dimensionless parameters can be derived from this equation. The sediment transport is accordingly characterized by

$$g_* = f\left(Fr_*, Re_*, \frac{\gamma_w}{\gamma_s - \gamma_w}, \frac{h}{d} \right) \qquad (2)$$

In this equation, the sediment transport per unit width and unit time is expressed by the dimensionless sediment transport number

$$g_* = \frac{g_s}{\rho_s \; d \; V_*} \qquad (3)$$

As a reference velocity V_*, the shear velocity as defined by Prandtl is used, which is defined by the bottom shear stress and

the density of the fluid.

$$V_* = \sqrt{\tau_o/\rho} = \sqrt{gh\ S} \qquad (4)$$

The parameters

$$Fr_* = \frac{\gamma_w}{\gamma_s-\gamma_w} \cdot \frac{h}{d} S = \frac{\gamma_w}{\gamma_s-\gamma_w} \cdot \frac{V_*^2}{gd}$$

$$Fr_* = \frac{\tau_o}{(\gamma_s-\gamma_w)d} \qquad (5)$$

is a modified grain Froude number, containing the ratio of the specific weights of the fluid and the submerged sediment. It corresponds to the shear stress parameter as defined by Shields.

The Reynolds number of the grain

$$Re_* = \frac{\sqrt{ghs}\ d}{\nu_w} = \frac{V_* d}{\nu_w} \qquad (6)$$

has been introduced by Shields in 1936 in this form.

By connecting the modified grain Froude number with the Reynolds number of the grain, a further dimensionless quantity can be defined.

Dividing Fr_* by Re_*^2

$$A_* \equiv \frac{Fr_*}{Re_*^2} = \frac{\gamma_w}{(\gamma_s-\gamma_w)} \cdot \frac{\nu_w^2}{gd^3} \qquad (7)$$

The expression A_* can be considered as a dimensionless buoyancy parameter, it contains exclusively the properties of the fluid and of the sediment and characterize the material properties of both media.

A.2 SEDIMENT TRANSPORT EQUATIONS :

Shields formulated from his experimental values the following relationship for sediment transport

$$\frac{q_s(\gamma_s-\gamma_w)}{q\ r\ s} = \frac{10(\tau_s-\tau_c)}{(\gamma_s-\gamma_w)\ d} \tag{8}$$

in which q_s and q represents the sediment and water volume per unit time and unit width.

Above equation can easily be transferred into the dimensionless quantities defined above.

$$\frac{g_s}{\rho_s\ d\ V_*} = g_* = \frac{V_m}{V_*}\ 10\ Fr_*(Fr_*-Fr_{*c}) \tag{9}$$

the term (V_m/V_*) represents the frictional resistance of the bed. This resistance depends upon Re_* and the ratio of the water depth to the roughness elevation or grain size (h/K_s) or (h/d).

H.A. Einstein introduced the concept of probability for analyzing sediment motion. On the basis of observations and probabilistic considerations, he found that the sediment transport depends upon the "transport intensity".

$$\phi = \frac{g_s}{\rho_s}\left(\frac{\rho_w}{\rho_s-\rho_w}\right)^{1/2}\left(\frac{1}{gd^3}\right)^{1/2} \tag{10}$$

and the "flow intensity"

$$\psi = \frac{\rho_s-\rho_w}{\rho_w}\cdot\frac{d}{(\gamma_{hy})_s\ S} \tag{11}$$

The relationship between the parameters ϕ and ψ is given in figure (A.1).

Einstein bed load function can easily be expressed in terms of the dimensionless parameters defined above.

For the transport intensity $\dot{\phi}$,

$$\phi = \frac{g_s}{V_* \rho_s d} \left[\frac{\gamma_w}{\gamma_s - \gamma_w} \right]^{1/2} \left[\frac{V_*^2}{gd} \right]^{1/2} = g_* Fr_*^{1/2} \qquad (12)$$

Reformulation of the flow intensity ψ yields

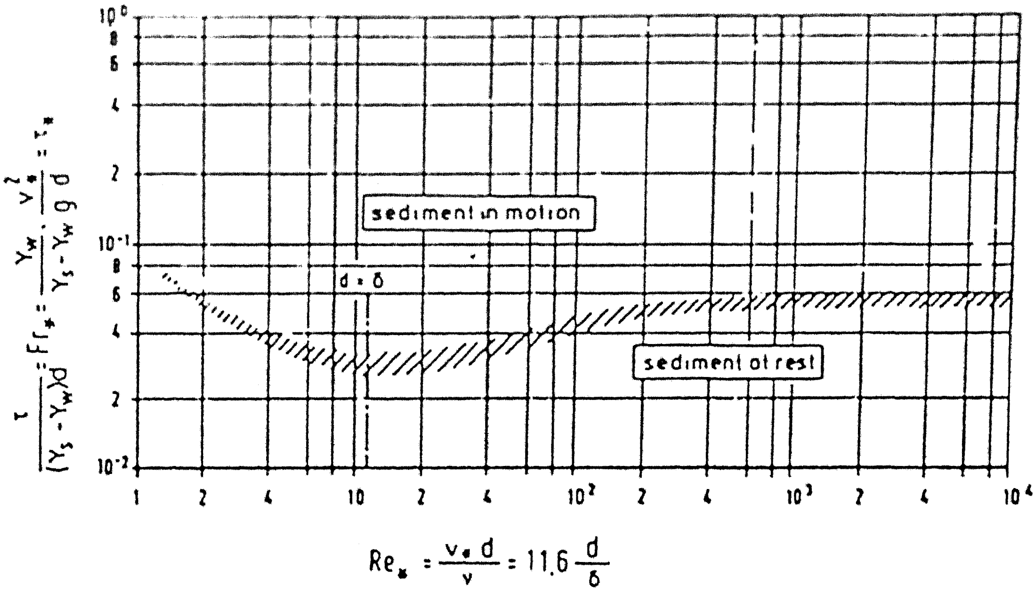
$$\psi = \frac{(\gamma_s - \gamma_w) d}{\tau_o} = \frac{1}{Fr_*} \qquad (13)$$

with these expressions, the Einstein bed load function can also be presented as a function of g_* and Fr_*.

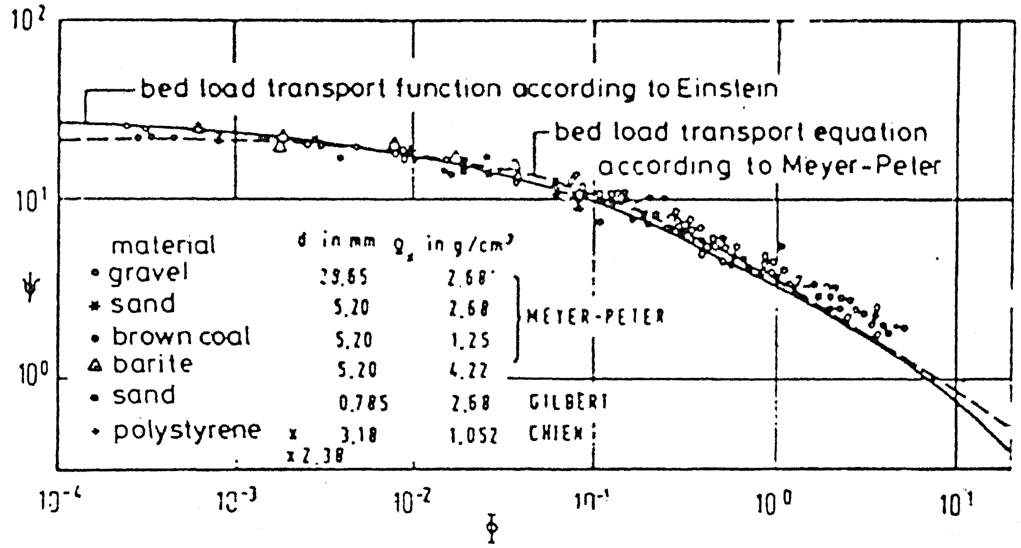
A.3 DERIVATION OF MODEL SCALES

It has been seen that the sediment transport is dependent upon the dimensional parameters Re_* and Fr_*.

If sediment motion is to be modelled correctly in a hydraulic model, then the model sediment and the model scales have to be chosen such that these dimensionless parameters have the same value in model and in nature. Furthermore, it is assumed that Froude similarity exists with regard to the hydraulic processes. If hydraulic similarity according to Froude's law is given, then one can derive the scale relationships by equating the Reynolds number of the grain and the modified grain Froude number in nature and model.



Shields Diagram



<u>Fig.</u> A·1 Bed Load Function of Einstein

$$Re_{*r} = \frac{Re_{*n}}{Re_{*m}} = 1 \ , \ Fr_{*r} = \frac{Fr_{*n}}{Fr_{*m}} = 1 \qquad (14)$$

For the derivation of model scales, one has to introduce now in addition to the length scales ℓ_r for horizontal lengths and h_r for vertical lengths two additional scale numbers. The grain size scale number

$$d_r = d_n/d_m \qquad (15)$$

and the scale number of the sediment density (under submerged conditions)

$$\Delta\rho_r = \frac{\Delta\rho_n}{\Delta\rho_m} = \frac{(\rho_s-\rho_w)_n}{(\rho_s-\rho_w)_m} = \frac{(\gamma_s-\gamma_w)_n}{(\gamma_s-\gamma_w)_m} \qquad (16)$$

If the kinematic viscosity and the specific weight of water is assumed to be equal in model and nature, then one obtains by equating the Reynolds numbers of the grain for model and prototype

$$Re_{*r} = \frac{g_r^{1/2} \ h_r^{1/2} \ S_r^{1/2} \ d_r}{\nu_r} = \frac{h_r^{1/2} \ d_r}{h_r^{1/2}} = \frac{h_r d_r}{\ell_r^{1/2}} = 1 \qquad (17)$$

Similarly, the modified Froude number in model and prototype can be equated if the specific weight of water is the same in model and nature, then one obtains with equations

$$Fr_{*r} = \frac{\rho_{wr} \ g_r}{\Delta\rho_r g_r} \cdot \frac{h_r}{d_r} \ S_r = \frac{h_r}{\Delta\rho_r d_r n} = \frac{h_r^2}{\Delta\rho_r d_r \ell_r} = 1 \qquad (18)$$

The scale relationships equations (17) and (18) yield in combination

$$h_r^3 = \Delta\rho_r \ \ell_r^{3/2} \qquad (19)$$

This equation resembles the scale relationship found empirically by Lacey and Inglis for models with mobile beds $\left[h_r^3 = \ell_r^2 \right]$.

In order to determine the correspondence between the model scales and the roughness related to the grain diameter, the Manning-Strickler equation can be used. For the roughness coefficient according to Manning-Strickler,

$$(K_{st})_r = \frac{l_r^{1/2}}{(h_r)^{2/3}} \qquad (20)$$

For a mobile bed, the roughness coefficient K_{st} can be determined from the grain diameter d_{90} (90% sieve passage) of the cover layer according to the empirical relation.

$$K_{st} = 26/d_{90}^{1/6} \text{ and with that}$$

$$(K_{st})_r = d_r^{-1/6} \qquad (21)$$

Now simple relationship can be derived between the horizontal and the vertical length scale

$$h_r = l_r^{0.7} \qquad (22)$$

A relationship between the scale number for the density of the model sediment and the scale of the grain diameter can be derived

$$d_r = \Delta\rho_r^{-1/3} \qquad (23)$$

The time scale for the sediment transport can be determined

by equating the dimensionless sediment transport number g_s in nature and model. If the transported sediment rate g_s, expressed as dry weight per unit width and unit time, is divided by γ_s, then one obtains the corresponding volume per unit width and unit time without void space. For sedimentation and erosion processes, one has therefore consider in addition to the natural structure of the bed, which depends on the grain sieve curve and other factors by introducing the void fraction p, relationship results

$$(g_*)_r \cdot p_r = \frac{\lambda_r h_r}{t_{s,r} \cdot d_r \cdot g_r^{1/2} \; h_r^{1/2} \cdot S_r^{1/2}} \; p_r = 1$$

and therefore $t_{s,r} = \dfrac{\lambda_r^{3/2}}{d_r} \, p_r$ (24)

For identical sieve curves in nature and model one can approximately assume (p_r = 1).

Then $$t_{s,r} = \frac{\lambda_r^{5/2} \; \Delta\rho_r}{h_r^{1/2}} \tag{25}$$

If the flow is assumed to follow Froude's law model law, then the time scale for hydraulic processes

$$t_{h,r} = \frac{\lambda_r}{h_r^{1/2}} \tag{26}$$

The time scales for sediment transport processes and for hydraulic processes in a model are not the same.

Average Ten daily Discharge in cumecs

River _ GANGA Site _ KANPUR

I - 1 to 10 , II - 10 to 20 , III - 20 to Last

Month	1960			1961			1962		
	I	II	III	I	II	III	I	II	III
Jan	153.6	148.39	151.4	269.42	316.05	249.24	374.56	314.18	317.95
Feb	159.72	142.56	114.27	384.04	707.52	458.94	565.55	420.94	328.01
March	93.8	129.7	165.1	266.43	202.65	167.26	303.77	537.46	397.52
April	125.82	91.38	80.85	148.24	122.17	105.48	247.47	176.26	132.52
May	60.5	52.1	42.12	92.95	81.69	72.73	151.19	135.35	96.33
June	43.93	47.43	180.38	64.73	394.98	633.53	93.7	141.62	397.44
July	422.81	3956.67	5281.15	759.64	3710.86	3136.5	678.88	908.72	2299.1
Aug	3671.16	4812.76	4641.81	6732.39	7087.24	9144.19	4576.85	3916.92	4040.13
Sept	4327.14	5238.75	1959.79	5974.16	3147.31	2069.46	4231.56	2581.02	4902.62
Oct	5355.63	4120.64	1128.87	1874.38	4368.41	1805.73	2187.49	978.49	666.84
Nov	863.8	695.34	448.06	1271.24	922.85	767.31	560.83	466.62	313.5
Dec	321.91	287.77	241.99	551.86	392.68	429.17	252.46	240.86	220.75

Month	1963			1964			1965		
	I	II	III	I	II	III	I	II	III
Jan	200.69	184.61	230.04	203.07	173.74	175.34	211.41	174.13	178.35
Feb	197.93	154.02	130.55	160.58	155.18	148.89	157.17	141.6	162.61
March	131.72	129.95	132.81	136.82	120.63	135.83	153.42	127.87	149.39
April	135.67	107.41	90.7	140.48	103.02	79.82	194.03	174.17	97.21
May	70.3	72.24	55.81	71.92	74.98	58.22	80.68	64.19	63.6
June	55.21	276.17	501.54	53.2	49.2	63.31	55.9	56.04	103.08
July	627.57	1288.75	1823.14	469.06	3182.98	3404.93	411.03	666.61	1849.03
Aug	3127.01	4473.51	7764.92	3684.48	3473.97	3789.24	2930.46	1983.66	1680.95
Sept	6987.03	4886.2	6703.02	4591.99	4285.81	3014.95	2277.91	2396.4	923.97
Oct	1901.07	942.89	696.35	3295.05	1262.64	936.87	430.2	319.63	270.14
Nov	673.99	714.76	439.29	760.77	581.94	443.67	181.31	167.07	151.29
Dec	291.43	260.13	240.38	307.49	326.46	290.44	129.06	108.63	109.17

Month	1966			1967			1968		
	I	II	III	I	II	III	I	II	III
Jan	95.48	74.4	75.02	114.16	111.28	94.23	373.39	373.44	321.74
Feb	81.94	81.89	92.71	85.21	84.18	73.38	266.66	226.85	200.79
March	83.84	67.27	55.08	67.64	68.33	68.64	220.43	174.59	168.16
April	46.0	43.48	39.69	79.43	62.26	54.59	181.94	122.75	139.48
May	36.69	43.3	56.26	47.94	42.84	40.39	151.19	125.97	72.48
June	34.18	29.76	301.58	28.33	173.01	314.23	56.75	243.31	805.51
July	2392.84	821.38	1955.05	878.25	1874.2	2931.73	1848.14	2271.09	4247.46
Aug	4875.73	7100.54	4559.86	3344.83	6099.57	6775.13	2622.55	3908.74	4077.30
Sept	2301.4	1951.07	1254.27	9232.82	5338.9	2524.33	1681.91	1120.29	1972.63
Oct	695.64	483.84	317.43	1257.25	726.18	444.2	887.74	498.56	351.23
Nov	204.38	180.18	147.31	352.66	421.2	348.65	265.14	233.16	203.89
Dec	141.32	136.92	123.06	267.82	256.57	250.22	169.87	136.06	124.38

Month	1969			1970			1971		
	I	II	III	I	II	III	I	II	III
Jan	120.54	122.81	123.65	171.81	153.04	195.13	122.32	116.06	116.33
Feb	116.53	114.51	100.6	236.54	197.71	221.73	118.23	101.92	93.68
March	91.51	82.44	80.41	279.59	297.52	230.8	100.48	111.29	89.61
April	69.33	59.14	56.02	175.02	134.3	115.24	75.74	68.04	80.04
May	52.76	57.83	45.27	95.35	64.23	65.56	68.17	75.66	74.73
June	54.38	271.97	293.59	86.24	341.85	621.96	148.94	1187.07	1770.31
July	468.39	1292.79	2573.18	960.72	1583.87	1797.97	3992.43	3772.81	3065.81
Aug	3263.95	3883.61	5176.1	2863.26	4830.42	3168.51	5481.77	8863.49	5170.5
Sept	2454.06	3367.64	5388.17	2912.77	3115.72	1917.63	7103.0	5630.05	1718.86
Oct	3637.56	1115.8	755.64	1315.37	987.21	666.68	1147.65	826.16	1966.06
Nov	828.86	562.63	386.73	451.74	281.5	232.94	1015.81	748.89	548.01
Dec	316.84	260.45	206.22	199.83	167.78	144.17	393.87	536.04	285.52

Month	1972			1973			1974		
	I	II	III	I	II	III	I	II	III
Jan	241.68	232.19	208.06	141.73	137.07	139.15	205.23	180.72	157.73
Feb	228.17	307.53	264.49	149.93	122.78	106.89	135.59	127.47	122.79
March	195.29	171.17	131.76	106.18	94.71	100.0	107.51	99.64	95.3
April	121.99	107 38	102.59	80.36	79.24	64.62	100.7	101.34	80.61
May	105.6	76 .97	67.04	69.9	208.6	128.92	69.91	115.45	95.47
June	103.65	111.72	210.01	128.06	449.95	2798.67	67.61	59.99	157.39
July	753.44	2906.12	1820.14	2079.43	2248.14	4245.06	202.52	490.45	2490.94
Aug	1302.93	1918.32	2647.32	6888.8	6742.65	5000.64	3721.01	4287.67	1795.38
sept	2540.53	5538.49	3399.76	3426.39	3235.87	2197.3	1684.94	855.22	573.88
Oct	1153.53	687.77	497.28	2068.54	1933.64	1004.28	444.08	283.82	239.12
Nov	477.36	321.27	251.66	652.42	468.63	367.08	162.23	132.5	116.29
Dec	230.84	216.51	199.93	310.79	272.61	231.73	100.96	90.07	97.2

Month	1975			1976			1977		
	I	II	III	I	II	III	I	II	III
Jan	95.13	87.24	79.05	168.07	154.67	141.64	126.4	108.06	121.56
Feb	70.31	68.67	67.12	136.45	122.23	137.93	156.45	146.74	123.43
March	63.39	55.86	51.38	131.8	102.58	97.81	116.27	96.47	85.13
April	46.74	43.13	40.14	91.91	84.19	89.07	77.28	80.35	69.52
May	33.46	40.64	91.9	106.2	77.52	100.54	68.19	64.3	63.3
June	92.11	129.55	1284.25	143.14	464.6	476.16	62.83	54.23	67.15
July	1476.4	1423.38	3106.9	420.66	1643.94	2694.75	515.27	3359.22	4796.81
Aug	4979.42	3529.32	3577.31	3607.11	3899.34	5974.19	4872.58	4126.9	2972.85
sept	3483.08	6705.69	3561.91	2812.14	2233.79	1191.87	3555.53	4024.83	3117.55
Oct	1790.88	1059.43	760.73	783.02	500.37	289.32	1704.74	1024.71	664.63
Nov	564.87	350.81	283.27	353.24	297.76	195.61	445.38	351.5	295.8
Dec	239.93	215.15	194.78	164.92	154.92	146.47	256.28	216.76	195.83

Month	1978			1979			1980		
	I	II	III	I	II	III	I	II	III
Jan	205.43	183.82	195.0	235.91	216.15	353.48	77.43	81.7	82.78
Feb	185.26	174.32	241.44	317.77	342.02	397.8	71.95	65.86	62.58
March	197.86	224.76	406.90	407.58	324.18	269.75	56.27	59.14	50.18
April	218.5	147.79	148.96	178.25	162.2	274.55	52.93	51.42	54.9
May	130.09	144.23	244.6	280.3	242.18	174.81	41.27	27.59	26.85
June	309.44	482.74	1522.8	133.51	125.18	316.83	30.8	133.42	353.65
July	3627.77	3962.04	3905.91	1015.72	1363.76	2416.3	1087.3	3052.99	5359.31
Aug	5576.2	10238.31	6470.86	2159.04	2321.47	2799.4	6333.26	5434.63	2485.08
Sept	7309.48	5469.67	2734.42	1059.0	650.2	373.01	2252.05	1860.57	1385.25
Oct	1506.44	885.06	774.15	214.47	140.97	116.04	753.16	494.28	392.81
Nov	629.41	429.54	320.54	97.35	90.43	92.32	390.9	238.14	180.15
Dec	319.14	385.89	313.9	97.9	89.89	85.83	166.03	150.29	152.69

Month	1981			1982			1983		
	I	II	III	I	II	III	I	II	III
Jan	155.24	135.23	130.19	106.59	129.30	129.65	160.52	157.16	134.25
Feb	142.36	121.26	102.82	160.56	137.68	122.85	207.54	225.50	143.62
March	89.46	96.87	106.39	114.46	196.21	166.27	113.46	96.86	96.27
April	83.55	108.33	118.22	163.80	119.70	106.33	82.28	86.18	277.64
May	71.23	65.90	60.14	205.96	235.51	277.74	251.11	179.67	239.71
June	82.74	102.90	99.83	153.95	189.16	499.01	301.05	308.05	267.26
July	1491.08	1704.74	3527.59	514.42	640.38	1972.22	1084.35	936.43	1130.77
Aug	5229.72	3374.09	2429.85	4141.89	3930.97	5673.15	2667.38	3777.59	4531.82
Sept	1420.47	771.00	554.25	6484.88	3289.28	1204.32	4508.89	5665.62	5569.90
Oct	663.94	392.62	220.24	560.69	319.64	246.35	3401.89	1946.22	924.64
Nov	196.38	220.13	197.51	238.70	219.83	192.41	647.08	432.16	336.99
Dec	155.34	135.78	117.80	172.44	138.10	153.70	287.66	270.38	260.72

Month	1984			1985			1986		
	I	II	III	I	II	III	I	II	III
Jan	274.41	225.84	240.67	127.41	123.67	123.26	369.44	285.17	223.81
Feb	191.27	186.90	228.20	115.01	100.28	94.08	239.44	331.70	361.99
March	218.64	143.95	125.19	83.31	74.80	71.10	276.99	197.38	186.40
April	132.43	124.98	125.61	74.13	64.44	63.60	171.19	124.14	104.60
May	101.07	133.50	116.45	60.74	59.14	58.25	108.77	91.67	141.80
June	152.06	599.02	1014.08	60.01	65.16	67.52	113.19	93.34	467.91
July	1542.78	1720.89	2218.65	157.76	526.69	2317.18	809.68	2812.87	4946.00
Aug	3020.30	1559.32	2292.94	2420.12	2939.20	5096.97	4458.70	3606.90	4957.01
Sept	4253.12	2755.87	1295.08	3229.94	3529.56	4016.93	1994.67	1151.20	784.29
Oct	649.28	541.80	430.74	1786.27	5078.88	3136.65	1153.41	718.42	569.52
Nov	255.98	197.31	167.40	1264.55	768.14	541.24	432.50	302.58	229.07
Dec	165.27	143.86	132.93	402.78	287.86	375.17	179.50	213.26	218.72

1987							
	I	II	III		I	II	III
Jan	157.98	150.79	166.68	July	102.84	400.49	585.59
Feb	158.31	137.92	147.36	Aug	901.08	744.79	708.71
March	142.44	125.45	111.88	Sept	1284.40	1386.93	927.79
April	102.63	87.1	71.34	Oct	643.16	183.08	140.66
May	82.05	97.14	78.18	Nov	103.62	118.02	91.64
June	64.94	146.55	185.55	Dec	76.55	71.66	62.21